**NAVAL FACILITIES ENGINEERING SERVICE CENTER**
**Port Hueneme, California 93043-4370**

# Technical Report
## TR-2088-OCN

# CLASSIFICATION AND MAPPING OF UNDERWATER UNEXPLODED ORDNANCE (UXO)

by

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December 1997



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During the summer of 1995, the Naval Facilities Engineering Service Center (NFESC) established a calibrated Unexploded Ordnance (UXO) test range offshore the Pacific Missile Range Facility (PMRF), Barking Sands, Kauai. The objective of the range was to provide an area that could be used to validate the performance of commercially available geophysical sensing systems for the mapping and classification of underwater UXO. The range included a calibration site and an operational site, and covered an area of 1.55 square nautical miles. The University of Hawaii Marine Minerals Technology Center (MMTC) conducted a demonstration effort on the range. Evaluation of the MMTC demonstration was performed by NFESC. A total of 257 inert ordnance pieces and 41 false targets were precisely placed on and under the seafloor in water depths from 1 to 50 meters. Targets ranged in size from groups of 7.62-millimeter cartridges to single MK83 bombs. This report describes the design, installation, and decommissioning of the range and includes a summary and evaluation of the MMTC demonstration activities.

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## EXECUTIVE SUMMARY


During the summer of 1995, the Naval Facilities Engineering Service Center (NFESC) established a calibrated Unexploded Ordnance (UXO) test range offshore the Pacific Missile Range Facility (PMRF), Barking Sands, Kauai. The objective of the range was to provide an area that could be used to validate the performance of commercially available geophysical sensing systems for the mapping and classification of underwater UXO. The range included a calibration site and an operational site, and covered an area of 1.55 square nautical miles. The University of Hawaii Marine Minerals Technology Center (MMTC) conducted a demonstration effort on the range. Evaluation of the MMTC demonstration was performed by NFESC.

A total of 257 inert ordnance pieces and 41 false targets were precisely placed on and under the seafloor in water depths from 1 to 50 meters. Targets ranged in size from groups of 7.62-millimeter cartridges to single MK83 bombs.

This report describes the design, installation, and decommissioning of the range and includes a summary and evaluation of the MMTC demonstration activities.


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# Naval Facilities Engineering Service Center

# 30 May 1997

## 1. Introduction

### 1.1 Background

Many coastal marine areas have been used over extended periods by the United States armed services and allies for simulated warfare training using live ordnance. The recent reduction of defense requirements has resulted in the closure of selected live ordnance training activities. Areas contain a large number of potentially dangerous ordnance items located on or under the seafloor. In addition to the danger to humans, the discarded unexploded ordnance (UXO) poses a potential threat to the environment. Estimated cleanup costs are in the billions of dollars.

Cleanup of UXO contaminated coastal land areas and their surrounding waters is necessary before government property can be returned to public use. The United States Navy has declared a 2-mile danger zone off some shores, but the area of primary concern regarding general public safety extends from the shore to the 50-meter contour. This is due to the fact that common usage of the seafloor, such as pleasure boating and SCUBA diving, do not extend significantly to deeper waters.

Effective methods to locate, classify, and map subsea ordnance must be demonstrated before contaminated areas can be cleared. Potential ordnance discarded in nearshore areas includes naval shells, bombs, rockets, torpedoes, mortar rounds, mines, and small arms ammunition. Some items may be found resting proud on the seafloor, but it is expected that a large percentage of items will be buried as a result of impact with the seafloor, sedimentary processes, or covered with marine growth. Finding and classifying these well camouflaged and sometimes buried objects provides a substantial challenge to cleanup personnel.

Over the course of the past 5 years, the University of Hawaii Marine Mineral Technology Center (MMTC) has developed techniques for quantitative mapping of seafloor mineral deposits. In particular, they have been investigating techniques for finding placer deposits. Placer deposits are an important class of seafloor minerals, consisting of concentrations of relatively dense minerals, such as gold and tin. These deposits are sorted naturally by wave and current action into shallow seabed accumulations. The occurrence of placer deposits is extremely difficult to predict using available geological and engineering models, and they are not easy to find and exploit because they are small.

MMTC has developed a number of tools and techniques for finding placer deposits. These tools could potentially be used for mapping and classifying underwater UXO. Placers are similar to ordnance in that they are smaller than most geological structures and consist of anomalous concentrations of specific materials in sites which are not easy to predict. Demonstration of the MMTC technology to detect and locate UXO was a major part of the effort described in this report.

### 1.2 Official DoD Requirement Statement

**1.2.1 Requirement Statement.** N 1.III.2.f. Improved Detection and Location of Unexploded Ordnance (UXO) on Land and Underwater.

**1.2.2 How Requirement was Addressed.** Hardware and procedures for the detection and location of underwater UXO were demonstrated and evaluated. The lessons learned and the hardware and procedures validated during the project work can be used during subsequent demonstration operations to advance underwater UXO detection and location capabilities.

### 1.3 Objectives

The Naval Facilities Engineering Service Center (NFESC) was tasked by the Environmental Security Technology Certification Program (ESTCP) to demonstrate and validate the use of the MMTC geophysical sensing technology for the mapping (detection/location) and classification of UXO in coastal waters. Because of a strong interest in the UXO cleanup of the land and near shore waters surrounding an island in the Hawaiian archipelago, it was desired that the technology demonstration for the project be conducted offshore an Hawaiian Island. The primary objectives of the effort were to:

- Design and install a test range which would consist of inert ordnance and other man-made targets placed on and under the seafloor at water depths ranging from 1 to 50 meters
- Demonstrate the use of the MMTC marine geophysical sensing systems for the classification and mapping of UXO (inert) on the range
- Recover the test range targets
- Evaluate the effectiveness of the MMTC systems demonstrated

### 1.4 Regulatory Issues

Over 25 sites have be identified that potentially contain underwater UXO. Cleanup associated with base closings is already underway at some of these activities such as Kaho'olawe and Mare Island. Other locations present hazards to dredging operations being conducted by the Corps of Engineers. Identified potential underwater UXO sites include:

Kaho'olawe, Hawaii
Great Lakes (6 sites)
Keyport WES
Fort Pierce, Florida
Erie Army Depot Camp Perry, Michigan
Attu Island, Alaska
Matagorda Island, Texas,
Charleston Army Depot, South Carolina
Lake Murray Bombing Range, South Carolina
Buckrue Beach, Maryland
Guam
Culebra, Puerto Rico
Potomac River
Aberdeen (Chesapeake Bay)
Duck, North Carolina
Dutch Harbor, Alaska
Matagorda Island, Texas
Raritan River, New Jersey
Baywood Park, California
Assteague Island, Maryland
Philippines
Azores

### 1.5 Previous Testing of Related Technology

During the planning stages of the Seafloor Target Mapping and Classification (STMC) range, a preliminary search was conducted to identify: (1) previous or ongoing efforts, if any, in the area of underwater classification and mapping of UXO, and (2) availability or history of previous ranges used for evaluation of UXO search equipment. It was discovered that while several organizations have worked with similar sensing equipment or similar types and shapes of UXO, none have evaluated their equipment with as extensive a combination of environment, sensing equipment, and target types used in the STMC range. A brief summary of the efforts identified is presented in the following paragraphs.

The Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV), Indian Head, Maryland, has been involved with a number of underwater ranges, as well as the design and fabrication of "mine-like targets." They control two underwater ranges both located in the Chesapeake Bay off Naval Air Station Patuxent River. Water depths range from 25 to 80 feet and the bottom type varies from firm sand with no obstructions to soft mud with large obstructions (mounds of oyster shells). The permanent range is seeded with mine shapes, typically MK36, MK52, and MK55. The temporary range is actually a test site for the Naval Air Station (NAS) and is littered with air-dropped inert ordnance, mostly 500-pound bombs and larger objects. Another Explosive Ordnance Detection (EOD) permanent range, planted with mine-like shapes, near Charleston, South Carolina, is maintained by EOD Mobile Unit 12.

The NAVEODTECHDIV recently formed an EOD Test Detachment, which has a charter to evaluate new technologies for clearing shallow waters (10 to 40 feet) in preparation for Marine amphibious landings. The 25-man team made up of personnel from Special Warfare (SPECWAR), Marine Reconnaissance (RECON), and EOD will be focusing their efforts on improving the mine detection equipment available to divers. If the team proves successful, they will continue their efforts to evaluate, improve, and transition commercially available equipment to EOD. The overall goal is to eventually remove the diver from the minehunting process by the year 2015 or 2020. Most of the testing is conducted with "Manta" and "Rockhound" mines installed off the coast of Coronado Island (San Diego, California). The mines are particularly difficult to find because they have glass reinforced plastic (GRP) casings and very little metallic content.

The bulk of EOD's underwater ordnance recovery involves preparedness exercises with mines, as well as an occasional real world assignment disposing of UXO. Some exercises have been conducted with targets as small as 5-inch to 54-caliber projectiles which were placed on the seafloor in known locations. Given general target location, EOD divers use hand-held equipment to pinpoint the objects and simulate recovery or disposal.

NAVEODTECHDIV prepared a report (Ref 1) on the search effectiveness of surface clearance techniques on Kaho'olawe Island in the Hawaiian chain. This report was based on testing done on land in December 1979 and January 1980. The results provided a basis for determining the types of UXO that might be found in the waters adjacent to Kaho'olawe. Every effort was made to secure similar inert shapes for use in the STMC range.

The Naval Command Control and Ocean Surveillance Center (NRaD), San Diego, California, is involved in training marine mammals to locate mines and other ordnance-like objects. The Marine Mammals Group maintains a number of small target fields off the coast of California near Pt. Loma and has also worked in ranges established off the coast of San Clemente Island. Targets in the Pt. Loma fields consist primarily of accurately positioned MK36 and MK52 mines. Water depths range from 10 to 200 feet, the bottom is sandy, and, while some of the targets are buried, most are left proud. The targets are moved frequently to minimize mammals "learning" the range layout.

The Naval Underwater Weapons Center (NUWC) Panama City, Florida, appears to be a leader in the investigation of technology for location of underwater mines and ordnance. Although they have been involved with experiments in water depths ranging from 0 to 1,200 feet, most of their work involves mine shapes and is conducted in relatively shallow water. The exceptions are a number of the larger air-dropped bombs which may also be armed with mine-like triggers and used as underwater mines. Investigations have involved testing numerous types of sensing equipment. NUWC Panama City does not have a permanent target installation. They use the beaches at nearby Air Force bases when there is a need for surf zone targets.

NUWC is currently establishing a tethered practice minefield in 240 feet of water off the coast of San Clemente Island, California. The range is to be used for shipboard training mine avoidance exercises. Thirty-seven-inch diameter steel spheres, used to simulate MK6 mines, will be tethered 60 feet below the surface. NUWC expects to have the field operational by mid October 1996.

Seatech Contracting Inc. (SCI) prepared a report entitled, "Unexploded Ordnance in Waters Surrounding Kaho'olawe: Historical Use, Estimates of Ordnance and Hazardous Materials, Technology Assessment for Clearance & Disposal, and Clearance Planning" (Ref 2). The report was prepared for the Kaho'olawe Conveyance Commission in July 1993. SCI used towed and free-swimming divers, towed video cameras, and a magnetometer to conduct a survey (coverage: 843 acres of a possible 7,259 acres) of the waters off Kaho'olawe. The report contains estimates of the types and quantities of UXO around the island.

The National Aeronautics and Space Administration (NASA) together with the Naval Surface Warfare Center (NSWC) Dahlgren Division Coastal System Station (CSS) and Jet Propulsion Laboratory (JPL) Pasadena, California, are involved with the development and testing of a multi-sensor tool - an acoustically quiet catamaran towing a suite of underwater sensors. The program, called Mobile Underwater Debris Survey System, or MUDSS, is to demonstrate various technologies that can be used to survey former defense sites for unexploded waste. The towed sensor suite consists of low and high frequency side looking sonar and SeaBat forward looking sonar, a cryogenically cooled magnetic field gradiometer, and a laser line-scanner electro-optic sensor. A separate JPL-developed instrument towed beneath the surface is a chemical sensor that samples the water to detect the presence of explosives. Feasibility testing was carried out at a demonstration range established in 30 feet of water in St. Andrew Bay, Panama City, Florida. Approximately 12 inert targets ranging from 60-mm mortar rounds up to 1,000-pound bombs and 55-gallon drums were arranged in a "clumped" pattern within a 22-meter diameter circle. An additional 12 targets were randomly placed in an area 18 meters wide by 150 meters long.

The U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi report, "Detection Of UXO Within A Sand Borrow Offshore of Seabright, New Jersey," discusses UXO detection (Ref 3). In 1994, the U.S. Army Corps of Engineers (USACE) and the State of New Jersey started the largest beach replenishment project ever undertaken in the United States. Shortly after dredges started removing sand from the established borrow area, a variety of ordnance items were discovered in the newly formed beaches. USACE conducted an investigation in order to determine if dredging could be carried out in certain areas of the borrow or if it would be more efficient to recover the ordnance from the seafloor. A survey vessel was equipped with underwater video cameras, a high frequency side-scan sonar, a sweep frequency sub-bottom profiler, and a cesium vapor magnetic gradiometer, and first tested against a calibration field. The calibration field included 18 pieces of ordnance buried 0.7 meters below the bottom and spaced 3 meters apart in approximately a 2-meter water depth. The final test involved five passes over the borrow area with each pass several miles long with 200-foot

separations. The report describes the performance of each piece of equipment and suggests that the analyzed data compares well with the typical characteristics of the ordnance accidentally recovered during the dredging operations. It is made clear, however, that no "ground truthing" was done to verify the actual performance of the sensor suite.

U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi report, "Beach and Underwater Occurrences of Ordnance at a Former Defense Site: Erie Army Depot, Ohio" was presented in January 1996 to the U.S. Army Engineer Division, Hunstville, Alabama (Ref 4). The Erie Army Depot was used for decades as a proving ground for a variety of Army artillery shells and other ordnance. Portions of the base have since been shut down and a cleanup effort is underway. When ordnance started "reappearing" after a September 1992 EOD sweep of the area from the waterline to 500 feet inland, USACE decided to conduct a study to determine the general location and concentration of ordnance and its potential to continue migrating back on the beach and toward a nearby shipping channel. The USACE's investigation covered onshore areas as well as the "nearshore" (1.75 to 4 feet of water) and "offshore" (4 to 12 feet of water). The sensors deployed included a magnetometer, and electro-magnetometer, a ground penetrating radar, side-scan sonar, and a remotely operated vehicle (ROV).

## 2. Technology Description

### 2.1 Description

The Marine Minerals Technology Center (MMTC), University of Hawaii, has been developing tools and techniques for quantitative mapping of seabed mineral deposits. Specifically, the work involves developing tools to locate placer deposits in the seafloor. Placers consist of concentrations of relatively dense minerals sorted naturally into shallow seabed accumulations. The tools and methods developed by MMTC and their collaborators for locating placers were evaluated in this demonstration effort. Specific equipment planned to be evaluated and items actually evaluated are described below.

**2.1.1 MMTC/OBD (Ocean Basins Division) Side-Scan Sonar.** This system consisted of an EG&G DF-1000 digital, dual frequency (100 and 500 kHz) towfish and digital conversion unit run by a newly developed topside processing software package hosted on a Sun workstation computer. The system was developed by Ocean Imaging Consultants (OIC) in collaboration with MMTC/OBD during the past 2 years. It permits unprecedented control of the sonar system and acquisition of the data with a full 12-bit dynamic range.

**2.1.2 Reson, Inc. SeaBat 9001 Multi-Beam Bathymetric Sonar**. This is the most compact, lightweight sonar currently available on a commercial lease. It surveys over a swath of 90 degrees across track (45 degrees above vertical to port and starboard) with a beam width of 1.5 degrees. It can be operated either from a towed or hull-mounted platform, and can be used at speeds up to 10 knots. It can be used in water depths from less than 5 meters to 600 meters. It

provides bathymetric data with resolutions approaching 5 centimeters. The system was mounted on an overboarding boom during the STMC range demonstration operations. To accommodate for the motions of the survey vessel, a pitch, roll, and heave sensor was deployed simultaneously.

**2.1.3 MMTC/CSD (Continental Shelf Division) Phased-Array Sub-Bottom Acoustic Profiler**. This system, developed and tested by MMTC/CSD, is basically a cross between a high resolution shallow profiling system and a reduced-scale 3-D oil-field seismic system. It is composed completely of components which are commercially available. An ORE Geopulse sound source is used to generate an impulse with a spectrum between 500 and 2,500 Hz within 3 dB of maximum output. It can be triggered at 0.25-second intervals to provide seabed and sub-surface resolutions of approximately 0.5 meters. It penetrates the seabed and retrieves useful returns to depths of more than 50 meters in carbonate sands.

A specially designed 24-channel hydrophone array receives the reflected energy from this source. It is constructed in three separate segments of eight channels each, with 1-meter group intervals. This can produce the 0.5-meter along-track common depth points for signal stacking. The three-hydrophone groups are tightly spaced so that, while they effectively cancel random noise, no high frequency signal loss occurs at extreme angles of incidence. An Elics Delph24 processing system is used to receive and digitize the data. This system can sample 24 channels at 12 kHz, sufficient for anti-biasing the broad-band Geopulse signals.

**2.1.4 Sea Engineering, Inc. Chirp Sub-Bottom Profiler**. During the past 5 years, frequency modulated ("chirp") acoustic systems have undergone extensive development and are available commercially. This particular system was developed specifically for high resolution profiling of carbonate sand bodies by Lester LeBlanc and Steven Schock, the original developers of chirp acoustic instrumentation. It has a lower frequency band than the other commercially developed systems (about 500 to 1,500 Hz). It is field tested and confirmed effective in carbonate sands in Hawaii for high resolution, shallow profiling to depths of at least 50 meters. The reflection data acquired by this profiler was processed using matched filter, resonance imaging techniques developed and applied specifically to this project by Dr. Alexandra Tolstoy, Section Head for Matched Field Inversion acoustic studies at the Naval Research Laboratory, Washington, D.C.

This system is very complimentary with the phased array system in that it provides the hydrophone receiving array with a frequency-modulated source for independent processing. Using the two systems together (but collected and processed separately) offered the advantages of the beam-forming offered by the hydrophone array (enhanced horizontal resolution) and the wide-beam resonance imaging capabilities of the chirp system. The chirp system can cover a much wider swath of seabed than the highly focused phased array system, and the phased array system can provide much more precise indications of location and depth beneath the seafloor.

**2.1.5 Geometrics, Inc. Model G-822A Cesium Magnetometer**. This instrument was planned to be used, but was not used during the demonstration. By using cesium instead of protons as the medium to measure the ambient magnetic field, it is possible to greatly improve the sensitivity and sampling rate over standard proton precession instruments. The G-822A has a potential sensitivity of less than 0.0005 nT/VHz RMS and a routine sensitivity of 0.003 nT peak-to-peak at sampling rates of 10/second. Geometrics, Inc. advertised that this instrument had been extensively field tested both in marine and land-based environments and that it had been proven to be sturdy and reliable. This system was reported to have the capability of detecting ferrous objects on and under the seafloor to burial depths of about 2 meters, when towed within 3 to 4 meters of the seafloor. However, less than 2 months prior to the start of the STMC demonstration operations, Geometrics reported that this system was not ready for field use.

**2.1.6 J.W. Fishers Mfg., Inc. Pulse 12 Time-Domain Electromagnetic Detector**. This sensor was planned to be used, but was not used during the demonstration. This sensor was reported to be capable of detecting both ferrous and non-ferrous metals on the surface and buried less than 0.5 meters. It had been extensively field tested and used by many salvage and treasure hunting operations. The system selected for use came with an altimeter for keeping the towfish a set distance off the seafloor. This system was advertised to be able to detect non-ferrous, but conducting objects, such as brass or other non-magnetic metals. It has a range slightly less than the magnetometer, but was originally thought to be essential since some of the targets may have been non-magnetic. The reason for not using this sensor is discussed in the demonstration operations section below.

**2.1.7 SETS Technology, Inc. Advanced Airborne Hyperspectral Imaging System (AAHIS)**. This system is a flight-tested, visible/near-infrared (432 nm to 830 nm), Hyperspectral (288 bands, effective band width of 5.5 nm/band) imaging system optimized for use in maritime and nearshore applications. It is a "pushbroom" type imager which builds the image line-by-line. Light is collected through a f/4 50-mm lens and an imaging spectrometer onto a 385 x 576 CCD, and then transferred through SCSI-2 interfaces to a computer hard drive, and ultimately to Exabyte tape. SETS Technology developed processing software which is specifically designed for detection and location of anomalous targets.

## 3. Site/Facility Description

### 3.1 Background

A site offshore the Island of Kauai in the Hawaiian Island chain was chosen for the demonstration for two primary reasons.

First, the site lies within the boundaries of the Pacific Missile Range Facility (PMRF), Barking Sands, Hawaii and therefore offers a controlled area which could be closely monitored on a "round the clock" basis. Extensive site data was readily available. Civilian pleasure and

commercial marine traffic can be restricted and operations can be planned and controlled without outside interference. Also, the range personnel would be available to expedite logistics and operational support.

Second, the PMRF test area is geographically close to the island of Kaho'olawe, which is expected to be a major future cleanup site. By being geographically close, it was expected that the seafloor bedrock would be basaltic material with similar magnetic signature properties. This would hopefully provide a realistic environment in which to demonstrate sensor performance.

In actuality, the very short time frame (less than 9 months) available following receipt of project funding for range installation and technology demonstration drove the final decision to conduct the demonstration at the PRMF Kauai. It would not have been possible to conduct detailed site survey and environmental permitting on an alternative site.

### 3.2 Site Characteristics

Kauai is the northernmost island of the Hawaiian windward islands and fourth largest of the eight major islands in the southeastern part of the archipelago (Figures 3-1 and 3-2).

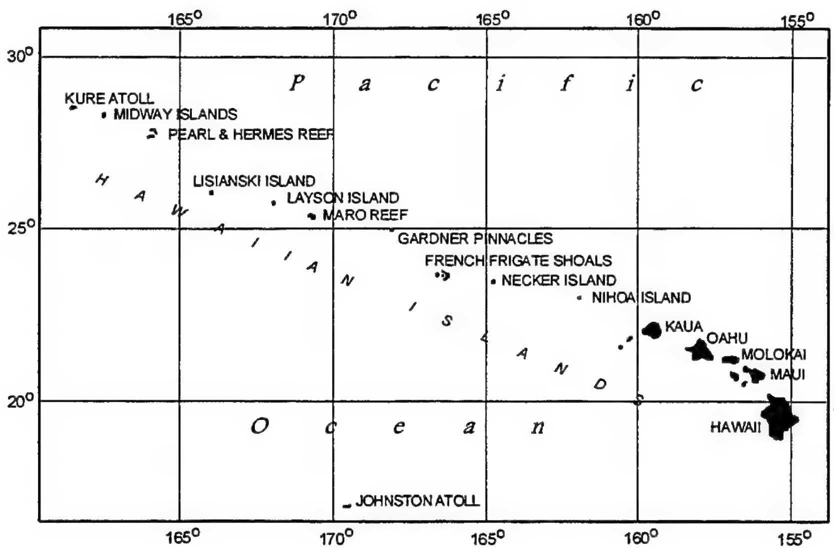


Figure 3-1. Hawaiian Islands

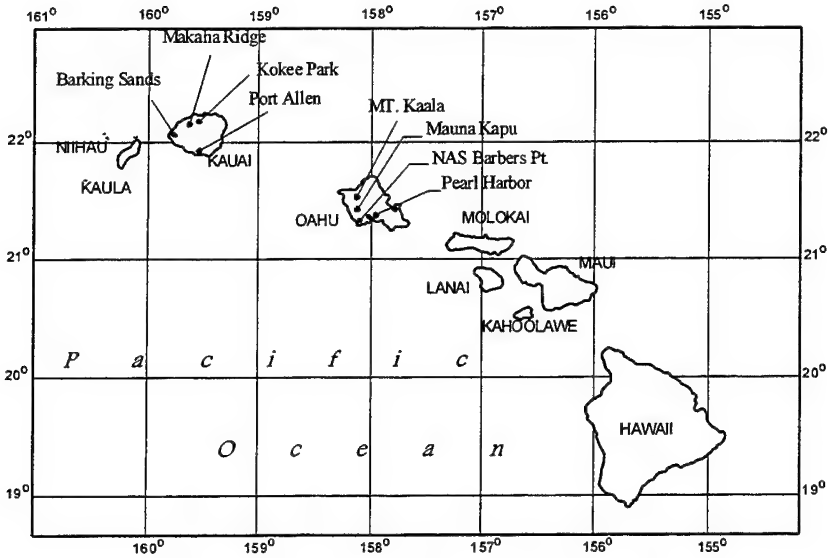


Figure 3-2. Hawaiian Windward Islands

Kauai measures approximately 33 statute miles east to west by 25 miles north to south. It is roughly circular, with a land area of 551 square statute miles (Ref 5). The Pacific Missile Range Facility (PMRF), Barking Sands is located along the western shore of Kauai. Figure 3-3 shows the location of PMRF and other landmarks on the island of Kauai.

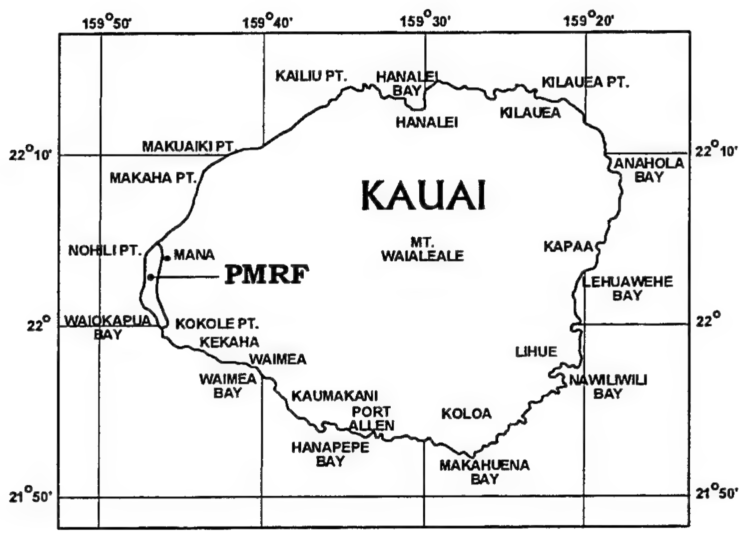


Figure 3-3. PMRF and Other Landmarks on Kauai

The climate on Kauai is mild and dry with only two meteorological seasons. Summer is April through November, and is a time of strong northeast trade winds. Winter is December through March, and is a time of lessening trade winds but increasing southeasterly winds and local storms. Air temperature on the island varies little over the year. The mean yearly temperature

measured at a weather station near Mana is 74.2°F, with a range in mean monthly temperatures of 70.1°F in January to 78.1°F in August (Ref 6). Precipitation varies greatly on the island. The areas west of the Mt. Waialeale Range receive much less precipitation than the rest of the island. For example, the annual rainfall near Mana is approximately 53 cm, and at Mt. Waialeale the annual rainfall is approximately 1,183 cm (Ref 7).

The waves off Kauai are composed of northeast trade waves, southern swells, Kona storm waves, and North Pacific swells. The summer months, particularly June, July, and August, have a much milder wave climate than the winter months. The northeast trade waves are generated by the prevailing northeast trade winds. They occur throughout the year but are most intense during the summer months of April through November. Northeast trade wave heights range from 1.2 to 3.7 meters and have periods from 5 to 8 seconds (Ref 8). These waves reach the PMRF site by refracting and diffracting around the northwestern and southwestern sides of Kauai. The southern swells are generated near Australia, Antarctica, and the southern Indian Ocean during the winter months of the Southern Hemisphere, which are the summer months of April through November at Kauai. These waves are long and low, with heights of only 0.3 to 1.2 meters and periods of 14 to 22 seconds. Their approach is from the southeast to southwest. Kona storm waves are generated by intense winds due to local fronts or Hawaiian lows usually during the winter. These waves are 3.0 to 4.6 meters high, with periods of 8 to 10 seconds. The direction of approach is from the southeast to west with the largest waves coming from the southwest. Kona waves occur infrequently, only 9 percent of the time in a typical year, but their intensity makes them a significant factor in the coastal processes of Kauai. Finally, North Pacific swells are products of storms in the Aleutians and of mid-latitude lows. They occur throughout the year but are most intense and numerous during the winter months of October through May. Wave heights are 2.4 to 4.3 meters, with periods of 10 to 17 seconds. The direction of approach ranges from northwest to northeast. North Pacific swells are some of the largest waves that reach Kauai.

More than one-third of all beach sand in the Hawaiian Islands is found on the beaches of Kauai. The islands of Niihau and Kauai have the largest beach sand reservoir per mile of coastline (Ref 9). Seasonal rates of erosion and accretion of the beach sand reservoirs are generally on the order of a few tens of cubic meters of sand per linear meter. The higher rates are on exposed north and west coasts. The Kauai beach sand is medium size, poorly sorted, and tends to move offshore during the winter and onshore during the summer. The primary source of sand is the marine life in the area, which produces calcareous sediments that are moved on shore by wave action (Ref 10). The secondary source is the Waimea River which carries sand-size materials into the ocean from the uplands of the island (Ref 11). Beach rock is prevalent and extends out to a 61-meter depth offshore Barking Sands (Ref 12). The beaches near PMRF are sand-covered during the summer months, and sand-covered with some exposed beach rock during the winter months (beach rock toward the north end of PMRF, sand toward the southern end of the facility). Figure 3-4 shows the variation in sand depth at a 6-foot pipe installed in beach rock near the northern end of the PMRF aircraft runway. Measurements were recorded for this figure from June 1983 to February 1984. The transition from summer to winter sand thickness is clearly shown.

A wide variety of seafloor conditions were found in the STMC range area. The different conditions were observed and documented during the range operations by divers, subsea video and 35-mm still cameras, and underwater remote sensing systems. Table 3-1 summarizes the seafloor conditions observed, and Figure 3-5 is an image taken during installation operations of a inert ordnance target and the seafloor just prior to the release of the target. Appendix B contains photographs representing the various seafloor types found in the range area, and photographs showing the seafloor condition at each target located in the range.

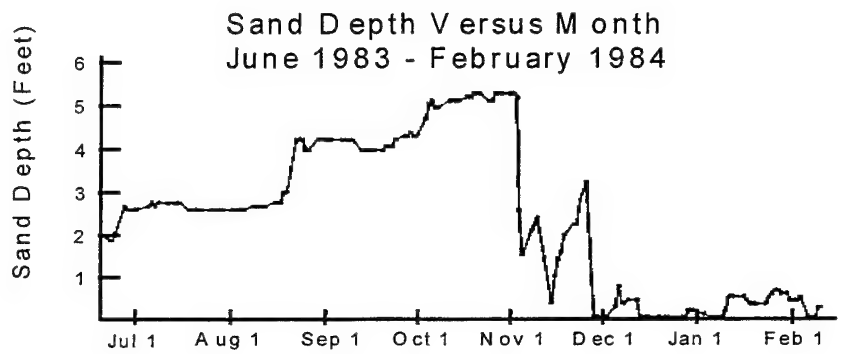


Figure 3-4. Summer/Winter Variation in Sand Depth Above Beach Rock (Ref 6) Near the North End of Kauai

Table 3-1. Summary of Seafloor Conditions Observed in the Barking Sands Range

| GENERAL DESCRIPTION | VARIATIONS |
|---|---|
| SAND | Smooth |
| | Bedforms (sand ripples and waves) |
| CORAL | Rubble and sand mix with red-brown algae ("Limu") |
| | Coral growth on rock |
| | Beach rock |
| ROCK | Outcroppings (flat and shaped) |
| | Ridges (maximum of 12 meters in height) |
| | Caves (assorted sizes) |

Figure 3-5. Typical Seafloor Conditions During Range Installation - Rubble/Sand Mix with "Limu"

The fluctuations of sea level around the island due to tidal forces are relatively small. The Waimea Bay (near PMRF) mean tidal range is 0.30 meter and the spring range is 0.49 meter (Ref 13).

Nearshore water currents are seldom more than 1 knot, except close to or within the area of breaking waves. Within the area of breaking waves, water currents of 3 knots or more have been measured. Water currents caused by tidal flow alone are typically around 1 knot (Refs 13 and 14).

The time of the year that the STMC range operations were conducted, July through September, was chosen because the summer months are the mildest with respect to wave action and sediment transport offshore of PMRF, Barking Sands.

**3.3 STMC Range Description**

The Seafloor Target Mapping and Classification (STMC) Range was installed at the PRMF Barking Sands facility during the period of 9-25 August 1995. A description of planning, installation, and recovery of the range is described in Appendix C. The physical layout of the range is shown in Figure 3-6. The range ran approximately 4.06 kilometers along the PMRF, Barking Sands shore, and extended approximately 1.48 kilometers seaward. The shallow water area of the range stopped south of PMRF housing so that project operations did not interfere with the summer beach and nearshore swimming activities in this area.

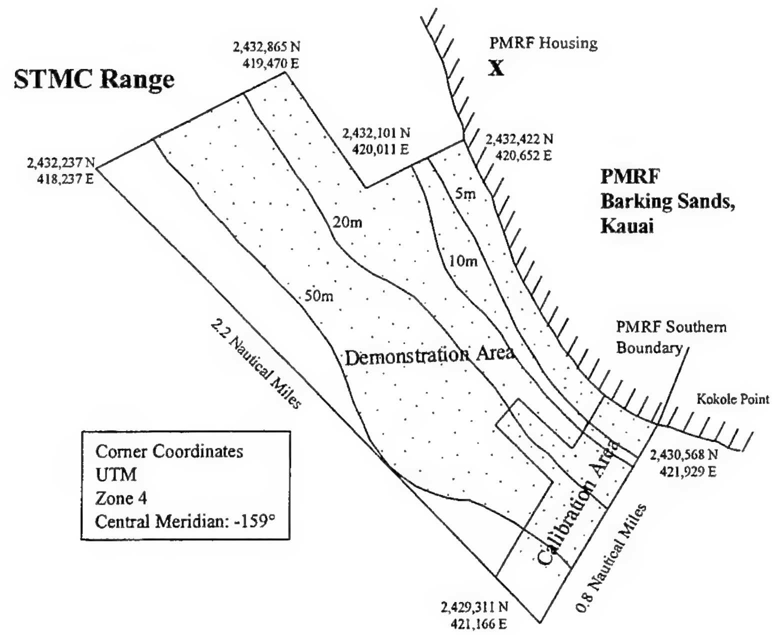


Figure 3-6. STMC Range Layout

The portion of the range that was offshore the housing area started approximately 0.5 nautical mile off the beach at a water depth of approximately 15 meters. The southern end of the range stopped at the southern boundary of PMRF. Water depths in the project area ranged from 1 meter to just over 50 meters. As shown in Figure 3-6, the calibration area of the range was located in the southern most section of the range, from shore out to just beyond the 50-meter contour. The surface area of the entire STMC range was approximately 5.30 square kilometers. The surface areas of the calibration and demonstration areas were approximately 0.67 square kilometers and 4.63 square kilometers, respectively.

### 3.4 Range Boundaries

The boundaries of the range were negotiated with PMRF and laid out in Universal Transverse Mercator (UTM) coordinates in Autocad. Defense Mapping Agency combat chart #808528 was used in conjunction with a digitizing tablet to digitize the shoreline and the seafloor contour lines in the vicinity of the range. Two geographic (lat-long) positions on the chart were converted to UTM coordinates to calibrate the chart and digitizing tablet in UTM coordinates. This combat chart is based on the North American Datum 1983. The conversions between geographic position and UTM coordinates were:

| | |
|---|---|
| Datum | WGS-1984 |
| Semi-Major Axis | 6378137 |
| Flattening | 298.257223563 |
| Central Meridian | -159 |

| | |
|---|---|
| Scale Factor | .9996 |
| North Parallel | 0 |
| South Parallel | 0 |
| Reference Latitude | 0 |
| False Easting | 500000 |
| False Northing | 0 |

The two points used to calibrate the chart and digitizing tablet and their corresponding UTM coordinates are:

| *Point* | *Geographic Position (NAD-83)* | *UTM Coordinates* |
|---|---|---|
| 1 | -159° 48' Long, 22° 00' Lat | 2,433,042.93 N, 417,421.38 E |
| 2 | -159° 44' Long, 21° 56' Lat | 2,425,628,96 N, 424,267.88 E |

This procedure ensured that the shoreline, contour lines, and all subsequent lines and points which make up the STMC range area were in actual UTM coordinates. It was understood that absolute geographical errors as great as 20 meters may be introduced by digitizing a chart by hand. However, these data were used for planning purposes only.

Table 3-2 gives the corner coordinates and areas of the entire STMC range, calibration area, and technology demonstration area. The corner coordinates given in the table start at the southern most point, and continue around the area in a clockwise direction.

Table 3-2. Range Boundaries - Corner Coordinates and Areas for Entire Range, Calibration Area and Demonstration Area (UTM Coordinates Zone 4, Central Meridian -159 degrees)

| **ENTIRE STMC RANGE** | | | **CALIBRATION AREA** | | | **DEMONSTRATION AREA** | | |
|---|---|---|---|---|---|---|---|---|
| **CORNER COORDS.** | | **AREA** | **CORNER COORDS.** | | **AREA** | **CORNER COORDS.** | | **AREA** |
| **NORTHING** | **EASTING** | **SQ. KM** | **NORTHING** | **EASTING** | **SQ. KM** | **NORTHING** | **EASTING** | **SQ. KM** |
| 2,429,311 | 421,166 | 5.30 | 2,429,311 | 421,166 | 0.67 | 2,429,602 | 420,874 | 4.63 |
| 2,432,237 | 418,237 | | 2,429,602 | 420,874 | | 2,432,237 | 418,237 | |
| 2,432,856 | 419,470 | | 2,430,212 | 421,244 | | 2,432,865 | 419,470 | |
| 2,432,101 | 420,011 | | 2,430,571 | 420,866 | | 2,432,101 | 420,011 | |
| 2,432,422 | 420,652 | | 2,430,739 | 421,020 | | 2,432,422 | 420,652 | |
| 2,430,568 | 421,929 | | 2,430,419 | 421,370 | | 2,430,762 | 421,579 | |
| | | | 2,430,762 | 421,579 | | 2,430,419 | 421,370 | |
| | | | 2,430,568 | 421,929 | | 2,430,739 | 421,020 | |
| | | | | | | 2,430,571 | 420,866 | |
| | | | | | | 2,430,212 | 421,244 | |

### 3.5 Target Placement Database

All targets were installed within the area constrained by the Barking Sands beach and the UTM coordinates given in Table 3-2 for each respective STMC range area. The range layout with the calibration target positions was completed in Autocad and output in DXF format. The DXF file was reorganized so that the data could be imported into Matlab™. The Matlab™ program provided a technical computing environment for numerical computation and visualization. An logarithm was then written in Matlab™ to randomly place the targets within the demonstration area (while complying with range layout criteria), estimate the depth of each target position based on the position of the target with respect to the contour lines, and randomly assign a target to each position. The resulting data then transferred to a database program for tracking and range installation documentation, and transferred to the installation navigation systems as navigational

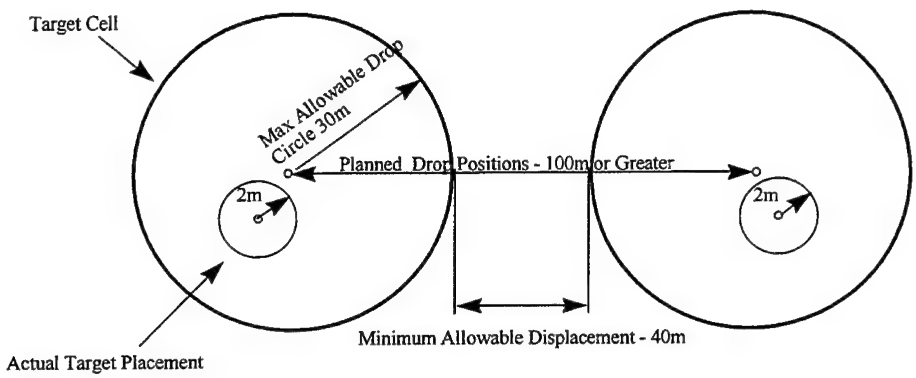


Figure 3-7. Target Placement Example

waypoints. An allowable drop zone of 30 meters around each target position was chosen. Figure 3-7 shows the approach used to plan the placement of the targets in the range. An analysis performed after completion of the project field work concluded that the accuracy of the target positions was better than ±2 meters (Ref 15). The analysis used navigation instrument manufacturer's information and data collected while in the field (for verification). Also, the actual placement position of each of the targets was determined to be approximately 10 meters or less from the planned drop positions of each respective target. This was due in a large part to the excellent maneuvering and station keeping abilities of the project vessel captain.

The planned installation position for each target was plotted and entered into a computer database prior to the start of the installation activities. Targets to be installed in water depths from 3 to 10 meters were to be secured to the seafloor with Manta Ray® anchors (plates driven into the seafloor). Targets in water depths from 10 meters to 15 meters skirted with small plastic

plates were used to prevent targets from rolling on the seafloor because of surge or wave action. Targets in the wash zone were anchored and secured to shore with small diameter wire rope.

The database also contained target background and tracking information, and as-installed and as-recovered data for each of the targets was filled in as the data became available. Selected information from the database is provided at the end of this report in Appendix D. Appendix D also contains as-installed plots of target positions in the STMC range. These plots are copies of plots #3 through #4 of Reference 15.

### 3.6 Calibration Area Target Distribution

Fifty-six targets (15 different types or classifications) were installed in the calibration area of the range shown in Figure 3-8. The calibration targets were selected as representative of targets placed in the operational area of the range. The minimum distance between each individual target was approximately 100 meters. Four rows of 12 targets were installed from 1-meter water depth to just greater than a 50-meter water depth in the large rectangular section of the calibration area. The targets in each individual row were similar in size, but were located at different water depths and rested in different orientations. One target in each row was buried. Eight targets were installed in the small rectangular area at the northwest side of the calibration area. Each of these was different in type, but each was installed on the seafloor at approximately a 20-meter water depth. No false targets were placed in the calibration area. A spreadsheet with the planned target installation data was provided to MMTC/OBD a month prior to the start of installation operations. The spreadsheet included:

- A description of the target at each position.
- Dimensions and weights of each target.
- Classification designations for each target (common name of the target, and size and weight class designations).
- A close-up photograph of each target.

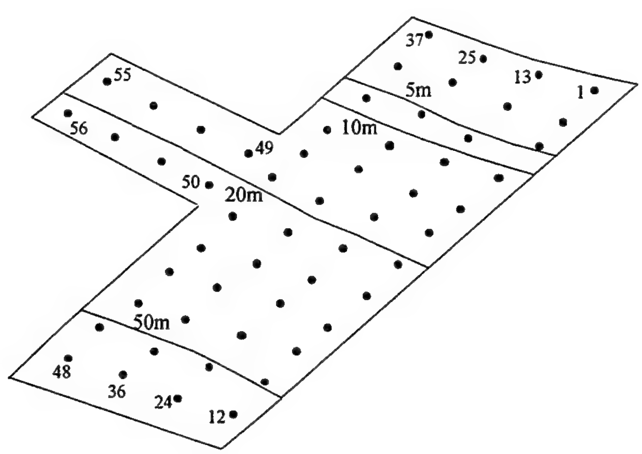


Figure 3-8. Calibration Area Target Distribution

As-installed data was added to the calibration data spreadsheet and provided to the demonstrator after the calibration targets were deployed, including:

- Actual target positions.
- Installed water depths and the orientation of each target with respect to magnetic north.
- A plot of the calibration target positions (as-installed).
- In-situ photographs of each calibration target showing the target and the local seafloor condition.
- A video showing each calibration target being released and laying on the seafloor. The video also showed the condition of the target and local surrounding seafloor at each respective calibration target position.

### 3.7 Demonstration Area Target Distribution

Table 3-3 provides a summary of the distribution of targets in the entire STMC range, the calibration area, and the demonstration area. There were 193 randomly distributed target locations in the demonstration area. The inert ordnance items installed in this area were identical in type to the pieces installed in the calibration area, but greater in number. All information regarding the demonstration area targets was considered sensitive. This information was not given to the demonstration team until after completion of their final mapping and classification report.

Table 3-3. Target Distribution Summary

| DISTRIBUTION DESCRIPTION | ENTIRE RANGE | CAL. AREA | DEMO. AREA |
|---|---|---|---|
| TOTAL NUMBER OF PIECES | 298 | 56 | 242 |
| INERT ORDNANCE PIECES | 257 | 56 | 201 |
| TOTAL TARGET LOCATIONS | 249 | 56 | 193 |
| INERT ORDNANCE LOCATIONS | 208 | 56 | 152 |
| FALSE TARGET LOCATIONS | 41 | 0 | 41 |
| GROUP TARGET LOCATIONS | 23 | 0 | 23 |
| BURIED TARGETS | 15 | 5 | 10 |
| **WATER DEPTH** | | | |
| * On Beach | 3 | 2 | 1 |
| ** 1 - 3 METERS (WASH ZONE) | 15 | 2 | 13 |
| ** 3 - 10 METERS | 27 | 8 | 19 |
| *** 10 - 50+ METERS | 204 | 44 | 160 |

*For calibration of airborne imaging system
**Very shallow water targets for airborne imaging system detection.
***Deeper targets for ship-operated sensing systems.

## 3.8 Target Descriptions

Inert ordnance targets ranged in size from groups of 7.62-mm cartridges to single Mk83 bombs. All inert ordnance targets were clearly marked as **INERT**. A serial number and an NFESC phone number were etched on each target in the event that a target was lost. The false targets used were items expected to be found on the ocean floor in areas that have ship traffic. These included items intentionally or inadvertently discarded by ships while at sea, or hardware found at or near the sites of shipwrecks. False targets included various sized steel or aluminum pipes, drums, chain, I-beams, box-beams, and grating. Sizes for the false targets ranged from 5.7-cm chain master links to 193-cm long pieces of 30.5-cm diameter pipe sections.

Table 3-4 provides the name or description of each inert ordnance and false target installed in the STMC range. Multiple pieces of each item listed in the table were installed. Appendix E is an identification guide for the inert ordnance and false targets that were installed in the range. This guide provides a drawing of each target (including dimensions and weights), and/or close-up photographs of each on land.

Table 3-4. Target Descriptions, Dimensions, and Weights

| NAME (MULTIPLES OF EACH USED) | LEN. (CM) | *DIA. (CM) | WT. (KG) | NAME (MULTIPLES OF EACH USED) | LEN. (CM) | *DIA. (CM) | WT. (KG) |
|---|---|---|---|---|---|---|---|
| INERT ORDNANCE | | | | FALSE TARGETS | | | |
| ** 7.62-MM CARTRIDGE | 7.1 | 1.0 | 0.05 | AMMO BOX (ANCHOR LINK INSIDE) | 43.2 | H33/W17.8 | 6.8 |
| ** AMMO BOX FOR 7.62-MM CARTRIDGE | 25.4 | ***H17.8/W8.5 | 6.8 | SMALL DRUM (FILLED WITH SAND) | 20.3 | 15.2 | 11.4 |
| 20-MM CARTRIDGE | 16.8 | 2.8 | 0.27 | MED. DRUM#1 (FILLED WITH SAND) | 30.5 | 25.4 | 15.9 |
| 40-MM CASING | 22.4 | 6.1 | 0.45 | MED.DRUM#2 (FILLED WITH SAND) | 40.6 | 25.4 | 22.7 |
| 2.75-INCH ROCKET WARHEAD | 27.9 | 6.6 | 2.7 | LARGE DRUM (FILLED WITH SAND) | 61.0 | 40.6 | 34.0 |
| 5-INCH ROCKET WARHEAD | 45.7 | 12.7 | 17.2 | SMALL STEEL PIPE | 45.7 | 7.6 | 3.6 |
| 7-INCH ROCKET BODY | 58.4 | 17.8 | 20.6 | MEDIUM STEEL PIPE#1 | 66.0 | 10.2 | 10.9 |
| 5-INCH 54-CALIBER CARTRIDGE | 88.9 | 12.7 | 13.0 | MEDIUM STEEL PIPE#2 | 91.4 | 11.4 | 15.0 |
| 5-INCH 38-CALIBER PROJECTILE | 53.3 | 12.7 | 24.9 | LARGE STEEL PIPE#1 | 116.8 | 20.3 | 50.0 |
| 5-INCH 54-CALIBER PROJECTILE | 66.8 | 12.7 | 31.7 | LARGE STEEL PIPE#2 | 193.1 | 30.5 | 142.7 |
| MK106 PRACTICE BOMB | 47.0 | 14.0 | 1.8 | ALUMINUM PIPE | 68.6 | 12.7 | 7.3 |
| MK76 PRACTICE BOMB | 63.5 | 16.8 | 10.9 | BOX BEAM | 76.2 | H12.7/W12.7 | 24.1 |
| FRAGMENTATION BOMB | 85.1 | 20.3 | 98.2 | I-BEAM | 61.0 | 10.2 | 11.8 |
| MK81 BOMB | 125.2 | 22.9 | 113.1 | STEEL GRATE | 87.6 | H2.5/W30.5 | 16.8 |
| MK82 BOMB | 168.9 | 28.0 | 226.2 | SMALL CHAIN (MULT. SECTIONS) | 91.4 | 0.6 | 13.6 |
| MK83 BOMB | 186.9 | 35.6 | 452.5 | LARGE CHAIN (SECTION OF LINKS) | 83.8 | 3.2 | 30.9 |

*Largest diameter used.
**Multiple 7.62-mm cartridges were placed in ammo boxes.
***H=height, W=width (non-cylindrical objects).

# 4. Technology Demonstration (MMTC Operations)

## 4.1 Background

Details regarding planning of the demonstration, at-sea operations, and data analyses that were performed is provided in the final technology demonstration report prepared by MMTC which is provided in Appendix F. The general sequence of events for the demonstration was as follows:

- MMTC conducted survey operations on the STMC range.
- MMTC conducted data analysis and provided NFESC with their "discovered" target data set (position and classification database).
- Immediately following receipt of the MMTC initial target discovered data set, NFESC provided MMTC with the installed target position and classification database.
- MMTC then revisited their data and provided a revised (final) target data set. Both data sets were analyzed by NFESC and the results are discussed later in this report

The MMTC final report provides a discussion of discrepancies between actual and detected target positions and classifications.

The sections below provide a discussion of the MMTC technology demonstration equipment and methods. Analysis and discussion of the MMTC discovered target set are contained in Chapter 5. The information provided was obtained from the following documents: (1) the MMTC progress report for 7 July through 7 September 1995 (Ref 16); (2) the MMTC Preliminary Project Results report (Ref 17); (3) the MMTC proposal for the demonstration of integrated commercial technology (Ref 18); and (4) the MMTC progress report titled, "Interim Report on Ordnance Location and Classification - Sidescan Target Prospects" (Ref 19). Reference 19 was the final data package sent by MMTC to NFESC (March, 1996).

NFESC supported the MMTC technology demonstration operations with a surface DGPS navigation system, a subsurface acoustic navigation and tracking system, an integrated navigation system, and a ship-mounted compass. These systems were the same used by NFESC during installation of the range and were already installed and available. MMTC personnel operated and maintained these systems during their demonstration operations. During MMTC demonstration operations, an NFESC representative maintained the DGPS shore station, acted as the STMC range consultant to the demonstration team for technical questions/problems, checked-in with PMRF for approval to enter the Barking Sands range, and served as the government representative for STMC operations.

Table 4-1 is the summary schedule of events for the MMTC demonstration activities. The detailed, day-by-day, schedule for the demonstration is provided in Appendix C.

Table 4-1. Demonstration Schedule Summary

| DATES (1995) | LOCATION | RESP. ORG. | OPERATION | DAY COUNT |
|---|---|---|---|---|
| 07/30 - 08/02 | Port Allen | MMTC | Setup/Move Eq. | 4 |
| 08/03 - 08/18 | Port Allen/Range | MMTC | Demonstration | 16 |
| | | | Total Days = | 20 |

## 4.2 Demonstration Approach

For the demonstration effort, the STMC range was divided into two environments. The first environment included the area of coastal seabed in the range from a depth of 5 meters to a depth of 50 meters. The second environment included the seabed from the shoreline to a depth of 5 meters. The first environment was surveyed using vessel-mounted or deployed sensors, and the second environment was surveyed by the SETS Technology AAHIS.

## 4.3 Pre-Demonstration System Assembly and Check-Out

The EG&G DF-1000 side-scan sonar system, Sea Engineering, Inc. chirp sub-bottom profiler, J.W. Fishers MFG., Inc. Pulse 12 time-domain electromagnetic detector, and AAHIS were operated briefly offshore Oahu to ensure that they functioned properly. The MMTC/CSD phased-array sub-bottom acoustic profiling system was assembled and checked out in the Gulf of Mexico, near the owner/operator's facility. The Reson, Inc. SeaBat 9001 multi-beam bathymetric sonar system was not available for at-sea testing prior to the start of the demonstration. This system was leased and the lease company performed bench testing with the system to verify proper operation prior to sending it to MMTC. Finally, the Geometrics, Inc. cesium magnetometer planned to be used was not used because the manufacturer claimed it was not ready for field operations.

Overall Assessment and Operational Results: All systems functioned properly. These operations provided an in-the-field training opportunity for the demonstration team members.

## 4.4 Bathymetric and Side-Scan Sonar Survey

The original MMTC plan called for the use of both a bathymetric and a side-scan system to collect water depth data, map potential targets on the seafloor surface, and identify areas of unconsolidated sediments. Due to malfunctioning of the side-scan sonar system, this preliminary survey was performed using the Reson SeaBat 9001 multi-beam bathymetric system only. The SeaBat provided bathymetric data, and the backscatter signal from this system was used to identify soft sediment areas in the range.

The SeaBat survey mapping was completed in 2 days. Three additional days were spent mapping areas of unconsolidated sediment, reconfiguring the survey vessel with two seismic systems, and attempting to repair the side-scan sonar system.

Overall Assessment and Operational Results: The SeaBat survey effort provided a seafloor contour map which was used for all subsequent survey work. It also identified unconsolidated sediments which narrowed the areas that were searched by other systems. The SeaBat produced excellent bathymetric data which were readily integrated into the survey process. The bathymetric data were found to be very consistent from line to line and were accurate to within approximately 2 meters with respect to water depth, with horizontal resolutions of a few meters. The system was a good compliment to the side-scan sonar system (used later in the demonstration), producing quantitative data to remove some of the ambiguity of the time-series returns received by the side-scan system. The SeaBat system was very inferior to the side-scan sonar system for identifying sediment variances, both in terms of the dynamic range of the returned signal and the available swath width. Two large areas in the range were identified which consisted mostly of sand deposits. These two areas were used during the subsequent shallow-reflection profiling surveys. The SeaBat system is more efficient than single-channel bathymetric mappers, but it has a much smaller swath width than side-scan systems. Since its area of coverage is confined to a 90 degree angle below the vessel, it covers relatively small areas, particularly in shallow water. It was not possible to retrieve saturation coverage in the test range with this system, and bathymetric depths were inferred between swaths in the shallow half of the range.

Hard-copy mosaics of the bathymetric and backscatter data, and data tapes of the original acquisitions (indexed to UTM coordinates) are included with the final MMTC report. A qualitative comparison between the backscatter data from the SeaBat with the side-scan data is also provided.

### 4.5 Training in the Calibration Area and Seismic System Operations

The time-domain electromagnetic pulse system was planned to be used as a classification device for targets located by the other instruments. During previous testing, anomalies detected with a standard proton precession magnetometer were investigated using the electromagnetic sensor, and good correlation was noted. Very small anomalies found with the magnetometer were very significant for the electromagnetic sensor, while large, probably bedrock-induced anomalies were not detected. However, when the electromagnetic sensor produced a significant signal, its baseline value shifted markedly, and it was not possible to repeat readings with any reproducibility. Because of these and other problems, MMTC decided not to use this system in the STMC demonstration. The tool might be useful in the future if a stable baseline can be achieved.

The chirp and the phased-array acoustic sub-bottom profilers were the only systems used during training in the calibration range. During this training, the detection ranges and special

characteristics for these two sensor systems were carefully documented for each target type and then incorporated into search strategy for operations in the demonstration area of the range.

Survey legs were conducted parallel to the coast using the DGPS navigation system, digital compass, and integrated navigation system. Tracking of the subsurface sensors was attempted with the NFESC subsurface navigation and tracking system. This task was completed in 3 days. Four days were then spent to post-process the data collected, develop the survey plan for the final operations in the demonstration area, and to repair and test the side-scan sonar system.

Overall Assessment and Operational Results: Because the chirp sub-bottom acoustic profiler by itself can retrieve data only from a very narrow swath (< 3 meters) directly beneath the towfish, its application for practical ordnance location and classification depends upon the use of other sensors to narrow the field of survey. The chirp system provided an excellent real-time characterization of the seabed type, which was very useful for confirming the presence of soft-substrate seabed types identified by the SeaBat backscatter records. The chirp system proved to be a very well designed and robust system. Its only negative operational attribute was the size and weight of the towfish (approximately 1.2 meters x 1.5 meters x 0.9 meter; 364-kilogram weight in air), which makes deployment and recovery much more difficult than other systems and requires special handling for shipment. No analysis of the data retrieved by the chirp transducers was performed.

The MMTC/CSD phased-array sub-bottom acoustic profiling system consisted of a specially designed 24-channel hydrophone array and an ORE Geopulse sound source. Reduction of the multi-channel seismic data collected with the hydrophone array for high resolution imaging is computationally intensive. Because of this, it was not possible to use the system to provide real-time "quick look" solutions. Radio frequency noise from a land-based commercial radio transmitter adjacent to the test range proved a challenge to the collection of data. Repositioning of the data-acquisition computer to the vessel's fantail was required to minimize above-water cable exposure to the noise. Clearly, digital conversion at the receivers would greatly improve this technique by reducing the source of noise dramatically. Also, Precision Signal, Inc., the designer and manufacturer of the chirp sound source, declined to provide the signal profile necessary for matched filter processing. MMTC/CSD sampled the outgoing signal from the system using a calibrated hydrophone. This sample was used in the processing of the chirp signal. All in all, the system functioned as designed, and the field adjustment made to the system (repositioning the computer), together with favorable sea conditions, resulted in the collection of good data.

### 4.6 Demonstration Area Side-Scan Operations

The demonstration team used a side-scan sonar system to map targets on the surface of the seafloor and to verify areas of unconsolidated sediments where targets might be buried. Likely targets (small targets with high backscatter) were selected ("real time') from the incoming data stream. Selected 250 x 250 pixel samples around potential targets were recorded in separate

files. The potential target data , and other potential targets identified later during data post-processing, were analyzed in detail to hypothesize target classifications.

Survey legs were conducted parallel to the coast. Vessel navigation data was acquired using the DGPS system, digital compass, and integrated navigation system. Tracking of the side-scan fish was attempted with the NFESC subsurface navigation and tracking system.

This task was completed during the last 2 days of demonstration activities on the STMC range.

Overall Assessment and Operational Results: Mechanical problems with sealing the towfish electronics led to failures which resulted in the side-scan sonar not being available until late in the demonstration operation. As a result, side-scan data did not provide complete coverage over the range demonstration area. Because of these failures, the system was not used at the start of the demonstration as planned but was used at the end. Other problems were encountered with sub-surface tracking of the towfish requiring later interpolation of position using hand layback calculations. As a result, extensive post-processing of the side-scan data was required.

Another significant problem encountered by the demonstration team was that the system's time-varying gain (TVG) was incorrectly set by the manufacturer and could not be adjusted in the field. The result was that this data channel was clipped severely. As a result, only the near-field (<20 meter lateral on the seabed) data were usable. This reduced the range of detection for the system at the higher resolution (500 kHz).

Two data acquisition systems were used during the side-scan survey operations: (1) an Ocean Imaging Consultants (OIC) workstation-based system, and (2) a PC-based system. The OIC system had significantly better real-time observation capabilities and thus offered better opportunities for rapid target identification. The relatively high spatial resolution and high dynamic range of the workstation display could not be matched by the PC display. However, the PC-based system is considerably more robust and was easier to operate.

### 4.7 AAHIS Calibration and Demonstration

The demonstration planned to utilize the SETS Technology Advanced Airborne Hyperspectral Imaging System (AAHIS) to conduct surveys in the shallow water wash zone. This system is deployed from a small aircraft. However, due to operational problems, SETS technology did not produce mapping or classification information for any targets.

Overall Assessment and Operational Results: A calibration panel placed on the beach was stolen before the overflight in the STMC range occurred. Theft of the calibration panel severely limited data processing options for the data collected.

The highest spatial resolution possible with the AAHIS was limited chiefly by the turbulence-induced motions of the aircraft. These effects were mitigated somewhat by an inertial navigation

system in the aircraft, but the ultimate pixel size was still limited to approximately 1 meter. Targets which were significantly smaller than this size can be detected when their contrast with the ambient spectral pattern is sufficiently strong to produce a significant difference between the overall spectral pattern for the pixel in which they lie and its neighbors. The AAHIS was successful in detecting sub-pixel sized targets placed on the beach (two 2.75-inch rocket warheads and a MK76 practice bomb) because they met these criteria. The reduced spectral variability caused by sea-surface reflections and light scattering by the seawater itself, however, left insufficient contrast for detection of the seabed targets in the range.

### 4.8 Vessel-Mounted Navigation Systems

The NFESC navigation systems used by the demonstration team included a Differential Global Positioning System (DGPS) vessel-mounted unit, a digital compass, an Ultra-Short Baseline (USBL) sub-surface acoustic navigation and tracking system, and an integrated navigation system. All of these were the same systems that functioned flawlessly during the NFESC at-sea operations conducted before and after the demonstration (descriptions of these systems were included earlier in Section 3.3.1). MMTC also leased a vessel-motion compensator for the demonstration activities. All of these were operated and maintained by the MMTC team during the demonstration operations.

Overall Assessment and Operational Results: With one exception, these systems performed satisfactorily and provided the necessary data for target location. The DGPS provided excellent surface position data with no significant downtime. Ship and airplane positions collected are believed to be accurate to less than 2 meters, based upon positions retrieved on the beach at known locations. The vessel-motion compensator also performed well and greatly improved the quality of the bathymetric data obtained. The navigation integration software and computer proved to be well designed and capable of efficiently collecting and reducing the key navigation data and reporting the reduced results to all of the data acquisition platforms.

Unfortunately, the USBL sub-surface acoustic navigation and tracking system did not interface well with the acoustic sensors and placed severe limits on the navigational accuracy for these systems. Significant acoustic cross talk was observed between the sub-surface navigation transponder signal and the side-scan receivers, causing unacceptable noise on the side-scan records and precluding continuous operation in the transponder mode. Also, poor tracking of the deployed system was observed in the responder mode, particularly when the system was close to the ship in shallow water depths. However, some good fixes were obtained in the relatively deep deployments. Finally, MMTC reported that they could not obtain offset information with the sub-surface acoustic navigation system for transponders placed on the water surface-towed acoustic hydrophone arrays. This is a common problem. The acoustic tracking system operates best (by design) when beacons are tracked well below the water depth of the hydrophone head for the system. Also, water surface and vessel noise can interfere with the acoustic tracking signals, especially when the a beacon is being tracked very near the surface or vessel. Finally,

there can also be problems with signal reverberation and multi-path in shallow water and near water surface operation.

# 5. Demonstration Performance Assessment

## 5.1 Analytical Methods

**5.1.1 Approach.** The assessment of the demonstrator's performance was modeled in part from similar work conducted at Jefferson Proving Ground during the Unexploded Ordnance Advanced Technology Demonstration Program (Refs 20 and 21). Table 5-1 lists and describes the parameters used for the assessment. These are not exactly the same parameter names and definitions as used at Jefferson Proving Ground. As a result, the performance ratios have slightly different meanings than those used in the Jefferson Proving Ground reports. Only the definitions contained in this report were used for the STMC demonstration assessments.

Table 5-1. Data Set Variables

| PARAMETER | SYMBOL | DESCRIPTION |
|---|---|---|
| Baseline Target Set (N) | BT = BO + BNO | All baseline targets |
| Baseline Ordnance Set | BO | Emplaced and existing ordnance |
| Baseline Non-Ordnance Set | BNO | Emplaced and existing non-ordnance |
| Demonstrators Reported Target Set (N) | DRT = DT + FDT | All targets reported by demonstrator |
| Detected Target Set (N) | DT = DO + DNO | All reported targets which match baseline targets |
| Multiple Detected Targets (N) | MDT | Single targets detected more than one time |
| Detected Ordnance Set | DO = TP + FN | Detected ordnance |
| True Positives | TP | Baseline ordnance detected and correctly identified as ordnance |
| False Negatives (R) | FN | Baseline ordnance detected and incorrectly identified as non-ordnance |
| Detected Non-Ordnance Set | DNO = TN + FP | Detected non-ordnance |
| True Negatives | TN | Baseline non-ordnance detected and correctly identified as non-ordnance |
| False Positives | FP | Baseline non-ordnance detected and incorrectly identified as ordnance |
| Falsely Detected Targets (N) | FDT=FDO + FDNO | Total of detected targets which do not correspond to any items in the baseline set |
| Falsely Detected Ordnance (R) | FDO | Detection's identified as ordnance that do not correspond to any items in the baseline set |
| Falsely Detected Non-Ordnance (R) | FDNO | Detection's identified as non-ordnance that do not correspond to any items in the baseline set |
| Undetected Targets (N) | UDT = UO + UNO | Total of baseline targets not detected |
| Undetected Ordnance | UO | Baseline ordnance not detected |
| Undetected Non-Ordnance | UNO | Baseline non-ordnance not detected |

Note: (N) denotes a new parameter definition not used at Jefferson Proving Ground.
(R) denotes a revision in the definition used at Jefferson Proving Ground.

The performance assessment was based on the comparison of the Baseline Target Set with the Detected Target Set. These target sets include both ordnance-like and non-ordnance-like targets. The Baseline Target Set includes all targets installed by NFESC.

Both the Baseline and the Detected Target Sets include the following data fields for each target:

| | |
|---|---|
| Northing: | Target's UTM northing (meters) |
| Easting | Target's UTM easting (meters) |
| Depth: | Target's depth below MSL (meters) |
| Type: | Ordnance-like or non-ordnance-like |
| Ordnance Class: | Practice bomb, projectile, rocket warhead, or other |
| Size Class: | Small (less than 10.2 cm dia.), medium (10.2 cm to 17.8 cm dia.), or large (greater than 17.8 cm dia.) |
| Weight Class: | Light (less than 9 kg), medium (9 kg to 45 kg), or heavy (over 45 kg) |
| Grouping: | Single or multiple |
| Burial State: | Buried or surface target |
| Heading: | Target heading with respect to true north in degrees |

NFESC provided these data to the demonstration team for each target in the calibration area prior to the start of the demonstration. The demonstration team (MMTC) provided the same data to NFESC for each object detected in the demonstration area. The priority for each of the data fields is in the order listed.

Table 5-2 is a listing of the inert ordnance used on the STMC range. The table gives the target common name, indicator, ordnance class, size class, and weight class for the inert ordnance targets that were installed in the STMC range. The mnemonic is the short item name used in reporting, computer processing, and presenting data.

Table 5-2. Class Definitions for Inert Ordnance Targets

| TARGET COMMON NAME | | MNEMONIC | ORDNANCE CLASS | SIZE CLASS | WEIGHT CLASS |
|---|---|---|---|---|---|
| 1. | 7.62-MM CARTRIDGE | CART762 | Other | Small | Light |
| 2. | 20-MM CARTRIDGE | CART20M | Other | Small | Light |
| 3. | 40-MM CASING | CASE40M | Other | Small | Light |
| 4. | 5-INCH 54-CALIBER CARTRIDGE | CART554 | Other | Medium | Medium |
| 5. | 2.75-INCH ROCKET WARHEAD | ROCK275 | Rocket Warhead | Small | Light |
| 6. | 5-INCH ROCKET WARHEAD | ROCK5 | Rocket Warhead | Medium | Medium |
| 7. | 7-INCH ROCKET BODY | ROCK7 | Rocket Warhead | Medium | Medium |
| 8. | 5-INCH 38-CALIBER PROJECTILE | PROJ538 | Projectile | Medium | Medium |
| 9. | 5-INCH 54-CALIBER PROJECTILE | PROJ554 | Projectile | Medium | Medium |
| 10. | MK106 PRACTICE BOMB | MK106 | Practice Bomb | Medium | Light |
| 11. | MK76 PRACTICE BOMB | MK76 | Practice Bomb | Medium | Medium |
| 12. | FRAGMENTATION BOMB | FRAG | Large Bomb | Large | Heavy |
| 13. | MK81 BOMB | MK81 | Large Bomb | Large | Heavy |
| 14. | MK82 BOMB | MK82 | Large Bomb | Large | Heavy |
| 15. | MK83 BOMB | MK83 | Large Bomb | Large | Heavy |

Comparison of the Demonstrators Reported Target Set (DRT), which did not contain any type or class information, with the Baseline Target Set (BT) was based solely on the target's position. The original plan called for basing the comparison of these data sets on position and type, but because the demonstrators did not classify their detections as ordnance or non-ordnance, a comparison by type was not possible. In order to grade the demonstrator, we assumed all targets in their Demonstrators Reported Target Set (DRT) were classified as ordnance type targets. The positions of the objects reported by the demonstration team were compared with the positions in the Baseline Target Set (BT). This comparison was used to split the Demonstrators Reported Target Set (DRT) into a Detected Target Set (DT) and a Falsely Detected Target Set (FDT). In addition, this comparison assigned all remaining Baseline Targets (BT) to the Undetected Target Set (UDT).

A critical radius ($R_{crit}$) was used to determine position matches. $R_{crit}$ is a radial distance from the positions of the Baseline Targets (BT). Only the Demonstrators Reported Targets (DRT) with positions that fall within the $R_{crit}$ of Baseline Targets (BT) are assigned to the Detected Target Set (DT). The $R_{crit}$ used for the assessment (31 m), and a discussion regarding how this particular $R_{crit}$ was chosen is provided in Section 5.2 (Assessment Results).

Next, if the Demonstrator had provided type information, the reported Type for each target would have been used to further split the Detected and Falsely Detected Target Sets (DT and FDT) into Ordnance and Non-Ordnance Target Sets (DO, FDO, DNO, and FDNO).

Finally, if the Demonstrator had provided type information, the Detected Ordnance Set would have been compared with the Baseline Ordnance Set to determine the True Positive Set and the False Negative Set, and the Detected Non-Ordnance Set compared with the Baseline Non-Ordnance Set to determine the True Negative Set and the False Positive Set. These data sets were to be the primary data used to determine demonstration team's performance. Because the demonstrator did not classify according to type, only the Detected Target Set and Falsely Detected Target Set were used in assessing the demonstrator.

**5.1.2 Detection Performance Assessment**. The Detection Performance Ratios describe the demonstrator's ability to detect targets similar to those in the Baseline Target Set, independent of the demonstrator's ability to classify or identify the objects. The following Detection Performance Ratios were planned to be used:

### 5.1.2.1 Overall Detection Ratio.

$$DR_{all} = \frac{TP + TN + FP + FN}{B} = \frac{All\ Detected\ Targets}{All\ Baseline\ Targets}$$

The Overall Detection Ratio ($DR_{all}$) is a measure of the demonstrator's ability to detect all types of the baseline targets, regardless of the demonstrator's ability to correctly identify them.

### 5.1.2.2 Ordnance Detection Ratio.

$$DR_{ord} = \frac{TP + FN}{BO} = \frac{All\ Detected\ Ordnance}{All\ Baseline\ Ordnance}$$

The Ordnance Detection Ratio ($DR_{ord}$) is a measure of the demonstrator's ability to detect ordnance-like baseline targets, regardless of the demonstrator's ability to correctly identify them. The probability of missed ordnance detection is the complement of this ratio.

### 5.1.2.3 Non-Ordnance Detection Ratio.

$$DR_{nonord} = \frac{TN + FP}{BNO} = \frac{All\ Detected\ Non\text{-}ordnance}{All\ Baseline\ Non\text{-}ordnance}$$

The Non-Ordnance Detection Ratio ($DR_{nonord}$) is a measure of the demonstrator's ability to detect non-ordnance-like baseline.

### 5.1.2.4 Small Target Detection Ratio.

$$DR_{small} = \frac{TP_{small} + TN_{small} + FP_{small} + FN_{small}}{B_{small}} = \frac{All\ Detected\ Small\ Targets}{All\ Baseline\ Small\ Targets}$$

The Small Target Detection Ratio ($DR_{small}$) is a measure of the demonstrator's ability to detect small targets, regardless of the demonstrator's ability to correctly identify them.

#### 5.1.2.5 Medium Target Detection Ratio.

$$DR_{med} = \frac{TP_{med} + TN_{med} + FP_{med} + FN_{med}}{B_{med}} = \frac{\textit{All Detected Medium Targets}}{\textit{All Baseline Medium Targets}}$$

The Medium Target Detection Ratio ($DR_{med}$) is a measure of the demonstrator's ability to detect medium-sized targets.

#### 5.1.2.6 Large Target Detection Ratio.

$$DR_{large} = \frac{TP_{large} + TN_{large} + FP_{large} + FN_{large}}{B_{large}} = \frac{\textit{All Detected Large Targets}}{\textit{All Baseline Large Targets}}$$

The Large Target Detection Ratio ($DR_{large}$) is a measure of the demonstrator's ability to detect large targets.

**5.1.3 Ordnance Typing Performance Assessment**. The Ordnance Typing Performance Ratios describe the demonstrator's ability to distinguish between ordnance-like and non-ordnance-like objects, independent of the demonstrator's ability to detect the items. The following ordnance typing ratios are defined, but because the demonstrator did not classify their detection by type these ratios could not be computed:

#### 5.1.3.1 False Negative Ratio.

$$FNR = \frac{FN}{FN + TP} = \frac{\textit{Incorrectly Typed Ordnance}}{\textit{All Detected Baseline Ordnance}}$$

The False Negative Ratio is a measure of the demonstrator's ability to identify ordnance items as ordnance, regardless of the demonstrator's ability to detect the ordnance. This ratio describes the probability that a demonstrator will report a detected ordnance-like item as non-ordnance and the item will go unremediated.

#### 5.1.3.2 False Positive Ratio.

$$FPR = \frac{FP}{FP + TN} = \frac{\textit{Incorrectly Typed Non-ordnance}}{\textit{All Detected Baseline Non-ordnance}}$$

The False Positive Ratio is a measure of the demonstrator's ability to identify non-ordnance-like items as non-ordnance, regardless of the demonstrator's ability to detect the non-ordnance-like item. This ratio describes the probability that a demonstrator will report a detected non-ordnance-like item as ordnance and unnecessary effort will be expended to remediate the item.

### 5.1.4 False Alarm Rate.

$$FAR = \frac{FP + FDO}{DRT} = \frac{\textit{All Targets Incorrectly Typed as Ordnance}}{\textit{Demonstrator Target Set}}$$

The False Alarm Rate (FAR) is a measure of the demonstrator's ability to distinguish ordnance-like items from any other target. It is dependent on the demonstrator's ability to detect the items because the Falsely Detected Ordnance is included. This measure describes the likelihood that a demonstrator will report false alarms and unnecessary effort will be expended to remediate the item. Because the demonstrator did not classify their detection by type, and because unknown target in-situ inspections were not performed, the FAR may be artificially high.

**5.1.5 Classification Performance Assessment**. The classification ratios describe the demonstrator's ability to distinguish between different classes of ordnance, independent of the demonstrator's ability to detect the targets. Four mutually exclusive classes used in this assessment are: large bombs, practice bombs, projectiles, and rocket warheads. Because the demonstrator did not classify his targets, these ratios could not be computed. For each of these classes, a separate classification ratio would have been computed by the following equation:

$$CR_x = \frac{\textit{Targets Correctly Classified as x}}{\textit{Targets of Class x Detected}}$$

Alternative sets of mutually exclusive class definitions can be used to determine demonstrator's ability to differentiate targets. For instance, the size data was used to compute classification ratios for the three different possible sizes of ordnance, and the weight data was used to compute weight classification ratios. The demonstrators were free to suggest an alternative set of mutually exclusive class groupings based on the results of processing the data from the calibration area.

## 5.2 Assessment of Demonstrator's Results

### 5.2.1 Discussion of Demonstration Operational Approach and Problems Encountered.

**5.2.1.1 Overall.** The demonstrator's planned approach to the problem, using a multi-spectral search to create a synergy that would increase the probability of detection, has merit. Unfortunately, various problems occurred just prior to and during the execution of the search which negated most of the synergy. Two of the sensor systems originally planned for the

demonstration were not used (the cesium magnetometer and electromagnetic detector), and no usable target detection data was obtained with the AAHIS. Also, the order in which the sensors were planned to be used was changed because of problems experienced with the demonstrator's side-scan sonar system. Originally, the side-scan sonar and swath bathymetric survey systems were to be used first to map the bathymetry of the range, locate areas of unconsolidated sediments, and identify and possibly classify (with side-scan sonar) potential surface resting targets. The other sensors were then to be used to detect buried targets in the areas of unconsolidated sediment, confirm the potential surface targets, and obtain additional classification data. The side-scan sonar was actually used last during the demonstration, and was the primary tool used for both the detection and classification of the targets. The demonstrator's search was reduced to:

- A swath bathymetry survey conducted 3 - 4 August 1995
- A seismic survey conducted 8 - 10 August 1995
- A side-scan sonar survey conducted 16 - 17 August 1995

**5.2.1.2 Navigation Problems**. Each of the three operations suffered in some way from navigation related problems. The swath bathymetry survey was unable to fully utilize the pitch, roll, and yaw sensor data because of the inability of the navigation computer to supply updated information at the rate needed by the swath system. The MMTC/CSD seismic system was unable to do 3-D multi-fold processing because the navigation system was unable to supply a "fire" command at the required shot point intervals, thus the seismic data was reduced to standard single fold seismic reflection processing. This was due to the fact that the navigation system was running under the Windows® operating system. In order to supply the "fire" command at the proper shot point interval, the system would have to have been running under the NT operating system. It should be noted that the number of buried targets was small. The buried targets were included to give a preliminary assessment of the 3-D technique and provide a data set that could be used to develop and evaluate target detection algorithms. These problems were the result of a lack of proper technical communications between all parties involved. The Naval Facilities Engineering Service Center had agreed to provide its surface and subsurface navigation systems to MMTC to make sure that all navigation was done to the same precision. MMTC decided to utilize the same integrated navigation system we had used, which was the Windows® based system. This system had all of the basic capabilities needed by MMTC but did not have the speed required for their application.

The side-scan sonar search was hampered by a cross talk between the transponder used to track the sonar towfish and the side-scan sonar. The use of the transponder was terminated. As a result, the navigational error reported by the demonstrators for the calibration range, where they were able to compare their detections with the known locations of the targets, was 35.4 meters on average, with a standard deviation of 20.

**5.2.1.3 Seismic Systems Approach.** The Seismic System was included to aid in the detection and classification of buried targets. The planned approach was to use the seismic system to map the area to determine areas where burial was possible and to use it as a tool to aid classification of targets that showed up on magnetics and electromagnetics but not side-scan sonar. No buried targets were detected using this system.

Because of the previously mentioned navigation problems, the seismic system could not be operated in 3-D (multi-fold) mode. This changes the system from a swath-type system to a system which gathers data along a single track line. For this seismic system to ensonify a target, it would require the seismic array to pass directly over the buried target. Multiple attempts were made to transit directly over the known positions of buried targets in the calibration area. However, due to the vessel moving off line because of water current/wind action, the sensors did not go over the targets of interest. A more detailed discussion of seismic operations is provided in Appendix G.

**5.2.1.4 Side-Scan Sonar Survey Approach**. Sensor and display resolutions will influence the operator's ability to detect targets which are ensonified by a side-scan sonar. The display resolution will generally determine the range and speed at which the survey should be conducted. As a general rule, a side-scan survey is planned so that the smallest target will be "pinged" at least three times. For a typical side-scan sonar to detect a square target with a 0.3-meter edge dimension (0.3-meter cube target), the speed of the vessel using a side-scan sonar at a 100-meter slant range would have to be 2 knots or less.

The cross-tract resolution is more complex and will determine the best side-scan sonar range to be used for a survey. A typical paper chart side-scan sonar recorder is 46 cm wide and displays a port and starboard channel, or 23 cm per channel. At a 100-meter slant range, this would result in a display scale of 11 meters per 2.54 cm, or 0.25 cm equals 1.1 meters. At a 50-meter range, this would be 0.25 cm equals 0.55 meters. For a high probability of detection, the minimum target and its shadow should use approximately 0.54 cm of the display. At a 100-meter side-scan sonar range, the previously discussed 0.3-meter cube target and its shadow would use 0.2 cm of the display. At a 50-meter range scale, it would use 1.0 cm of the display.

The demonstrators conducted the survey at 100- and 150-meter slant ranges and with a vessel speed of between 3 and 4 knots (average 3.3 knots). Based on the previous analysis, to find the 0.3-meter cube target, a survey should be conducted at a speed of 2 knots with the side-scan operating at a 75-meter slant range. The analog paper chart was used for this example to simplify the discussion. Many systems, including the demonstrators, are using digital images on a display screen. This would require a discussion of sample intervals and pixels, which is not necessary to understand the concept that visual detection of the target is dependent upon the visual presentation (size) of the target. The digital display of the data generally uses a smaller display width but has the ability to zoom in on areas of interest, providing a higher crosstrack resolution.

In order to ensure that every square meter of the range area had been surveyed, a parallel line survey would be laid out with a line spacing equal to the horizontal range of the side-scan sonar minus twice the navigational error. Thus, for a survey using USBL, the recommended survey parameters to detect a 0.3-meter cube target would be:

- Seventy-five (75) meter slant range
- Two (2) knot speed of advance
- Fifty (50) meter line spacing

The demonstrators used:

- One hundred and one hundred and fifty (100 and 150) meter slant range (300 meter slant range occasionally)
- Three to four (3-4) knot speed of advance
- One hundred (100) meter line spacing

A search for a target that is not symmetrical increases the complexity. If the target has significant aspect ratio (length/width), it is possible for it to be a great target along its length and a very poor target along its width. To overcome this, the side-scan survey is generally expanded to a grid, vice a parallel line survey. If the parallel line survey was an east/west survey, the grid would add a north/south set of parallel lines, at the same line spacing. This doubles the time of the survey, but significantly increases the probability of finding a target that has a significant aspect ratio. The contractor did not do a grid survey.

Also, the side-scan sonar survey was hampered by equipment problems which used up approximately 8 days of the 20 days available for the demonstration and resulted in only 2 days of side-scan sonar operation. A more detailed discussion of side-scan sonar operations is provided in Appendix F.

**5.2.1.5 Limited Area Coverage.** Only a portion of the range was covered with the demonstration sensors. The swath bathymetry system provided a bathymetric map of the entire range and data regarding soft-sediment areas, but no target detection data was obtained with this sensor. The MMTC/CSD phased-array and chirp seismic systems were only used in range areas identified by the bathymetry system to have unconsolidated sediments (where targets may have been buried), and the coverage (swath) of these systems was so small that very little of the areas these systems were used in was actually covered. The side-scan sonar system collected data from an approximate 10-meter water depth to the water depths found near the seaward boundary of the range, and no usable target detection data was obtained with the AAHIS. Therefore, no shallow water (1 meter to approximately 10 meters) detection data was collected. Table 5-3 contains the waypoints defining the areas covered with the seismic and side-scan sonar systems. Figure 5-1 shows the perimeter of the range, and the perimeters of the areas defined by the Table 5-3 waypoints. Figure 5-2 displays the positions of the targets installed in the range by NFESC

(demonstration area of the range only) and the perimeters of the areas defined by the Table 5-3 waypoints. The range perimeters and seafloor contour lines were excluded in Figure 5-2 for clarity. The area (triangle) where the seismic systems were operated is included in these figures for completeness, but it must be kept in mind that only a very small percentage of the seismic operational area shown was actually covered with these systems (very narrow swath).

The area of coverage for the side-scan sonar system was limited because: (1) the draft of the vessel (with safety factor) and wave action experienced offshore during the project operations prohibited the vessel from operating in water depths less than 10 meters; and (2) the maximum depth that the side-scan towfish could be deployed in the deep portion of the range was limited. The water depth that the side-scan towfish was able to be deployed (between 20 and 30 meters) was limited because the minimum speed (between 3 and 4 knots) that the vessel could effectively transit during the survey was not slow enough to deploy the towfish deeper without the use of a depressor weight on the towfish. Not anticipating this situation, a towfish depressor weight was not brought to the site by MMTC.

Additional details regarding range area coverage and problems experienced with the various sensors are included in Appendix F.

**5.2.2 Classification Approach and Calibration Area Detections**. The demonstration team separated target classifications into three groups. Side-scan sonar images of the known target types in the calibration area were matched with side-scan images of prospect targets in the demonstration area to assign classifications to these targets. The demonstration team reported in Reference 19 that the "examination of the prospects associated with calibration targets showed that the size of the image, particularly (if the prospect were) perpendicular to the vessel track, most consistently distinguished the targets which were large and heavy (Class 1), targets which were medium size and medium weight (Class 2), targets which were medium size and light weight (Class 3), and targets which were small and light (Class 4)." The demonstrators also reported that Class 1, 2, and 3 targets could be distinguished fairly well by this means, but the distinction between Class 3 and Class 4 was poorly expressed. Class 4 targets were detected less often in the demonstration area than in the calibration area. Therefore, it was decided that, in classifying the prospects in the demonstration area, only Classes 1, 2, and 3 would be used. Since Classes 3 and 4 were nearly indistinguishable from each other, Class 3 included the Class 4 targets.

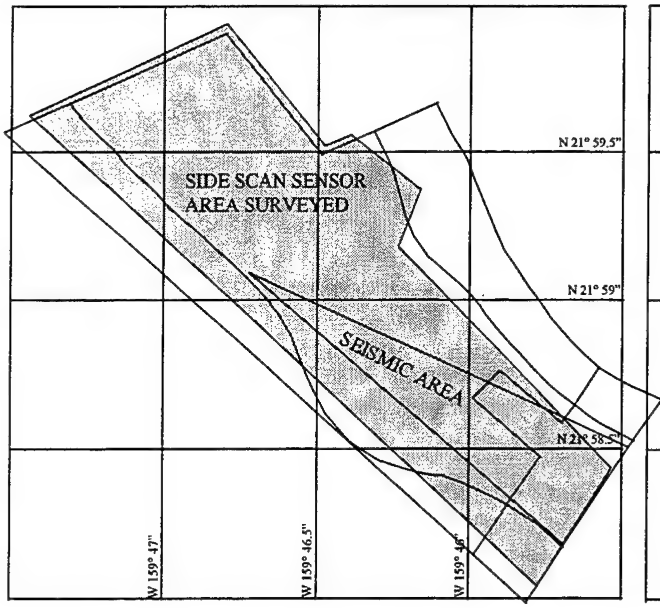


Figure 5-1. Range Perimeter and Detection Coverage (Sensor Area Coverage Shaded)

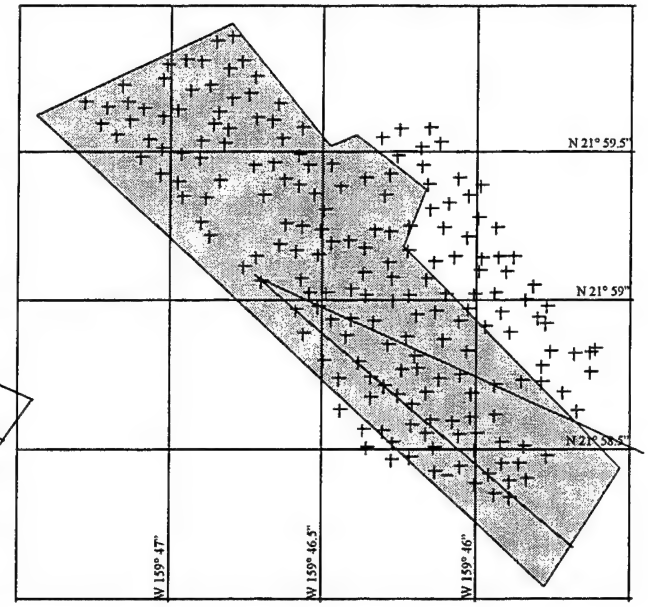


Figure 5-2. Target Positions and Detection Coverage

Table 5-3. Waypoints for the Areas Covered With Seismic and Side-Scan Sonar Systems

| SEISMIC AREA COVERAGE | | | SIDE-SCAN AREA COVERAGE | | |
|---|---|---|---|---|---|
| CORNER COORDS. | | AREA | CORNER COORDS. | | AREA |
| NORTHING | EASTING | SQ. KM | NORTHING | EASTING | SQ. KM |
| 2,429,656 | 421,370 | 0.87 | 2,432,342 | 418,388 | 3.8 |
| 2,430,273 | 421,744 | | 2,432,924 | 419,480 | |
| 2,431,357 | 419,596 | | 2,432,153 | 420,036 | |
| | | | 2,432,222 | 420,179 | |
| | | | 2,431,881 | 420,568 | |
| | | | 2,431,515 | 420,446 | |
| | | | 2,430,139 | 421,648 | |
| | | | 2,429,412 | 421,228 | |

Table D-2 of Appendix D shows the actual and detected data for targets in the calibration area of the range. No seafloor type information is included in this table. The entire calibration area was found to be relatively flat and sandy (see Appendix B for images showing the seafloor conditions at the calibration area target sites). The last field in Table D-2 ("position error") provides the distances between the NFESC installed locations of the calibration targets and the detected positions that were reported by the demonstrators. The position error data has a mean value of

35.4 meters, a maximum of 81.9 meters, a minimum of 3.2 meters, and a standard deviation of 20 meters. In assignments of duplicates, prospects less than 35 meters apart were considered to be the same object, and the lowest class number (largest and brightest acoustic return) was assigned to the prospect. The "site name" column in Table D-2 contains the target installation site names that were assigned by NFESC. Some site names are entered a number of times in the table. These sites were passed over by the side-scan sonar more than once (duplicates).

Twenty-six of the fifty-six targets installed in the calibration area were detected by MMTC. Two of the five targets buried within the area surveyed by MMTC were detected in the calibration area.

**5.2.3 Demonstration Area Baseline Target Set**. Of the 193 baseline (installed) targets in the demonstration area, 48 were not surveyed due to the reasons given in Section 5.2.1 (Area Coverage). Therefore, the demonstration assessment was based on 145 targets in the baseline data set. The distribution of the baseline target set is summarized in Table 5-4. See Table D-3 for a list of all the targets installed in the range (calibration and demonstration areas). Table D-3 contains site name, size and weight classification, position, water depth, burial depth, and seafloor type data for each target.

Note: The data required to evaluate the demonstration effort based on all of the targets in the range, regardless of the area covered by the demonstration sensors, is provided in the main body and appendixes of this report if a second party is interested. However, due to the problems that were encountered by the demonstrators it was decided that the best approach for the assessment was to only use the data in the area covered.

Table 5-4. Demonstration Area Baseline Target Set Distribution Summary

| ITEM DESCRIPTION | NUMBER IN DEMO AREA | NUMBER NOT SURVEYED | NUMBER USED FOR ASSESSMENT |
|---|---|---|---|
| Baseline Targets (BT) | 193 | 48 | 145 |
| Baseline Ordnance (BO) | 153 | 42 | 111 |
| Baseline Non-Ordnance (BNO) | 40 | 6 | 34 |
| Small Targets | 33 | 8 | 25 |
| Medium Targets | 132 | 38 | 94 |
| Large Targets | 28 | 2 | 26 |
| Buried Targets | 10 | 6 | 4 |

**5.2.4 Demonstration Area Detection Results.** Eighty-eight objects were detected in the demonstration area of the range. Table D-4 of Appendix D provides as-installed information, and the detection and classification data reported by the demonstrators for these targets. Figure

5-3 shows the perimeters of the range, perimeters of the area covered with the demonstration side-scan sonar system (shaded), the locations of the targets installed in the demonstration area of the range, and the positions of the 88 objects detected by the demonstration team. Each "+" in the figure represents the position of a target installed by NFESC and each "o" represents the position of an object detected with the demonstration side-scan sonar system.

Multiple entries of the same site name are made in Table D-4. When comparing the positions that the demonstrators reported for objects to the actual positions of the targets installed, the closest target site to each reported object position was assigned. Because a particular site was attached to two or more detected objects does not necessarily mean that the target at that site was the same object detected multiple times. The magnitude of the position errors computed in the table suggests that other objects (man-made or natural) could have been detected. Since unknown target in-situ inspection operations were not performed, the exact identity of each of the demonstrator's detected objects is not known.

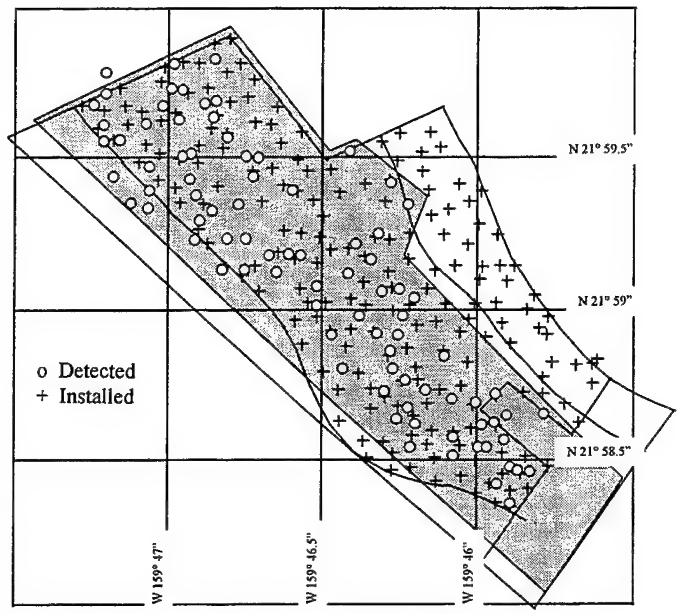

Figure 5-3. Range Perimeter, Side-Scan Sonar Area Coverage, and Installed and Detected Targets

Of the 88 objects reported, 68 individual target sites were assigned. The position errors reported in Table D-4 have a mean value of 68 meters, a minimum of 15 meters, a maximum of 205 meters, and a standard deviation of 39 meters. Four targets were incorrectly designated as buried and the two buried targets (0.1 burial depth each) at sites in the area surveyed were not reported as being buried objects. The target sites assigned to the object detections made by the demonstrators had the following seafloor types: smooth sand (11 sites); sand ripples (18 sites); sand waves (2 sites); rubble and sand (20 sites); rubble and sand with coral (2 sites); rubble and sand with algae (12 sites); rock outcrop flat (2 sites); and sand ripples next to rock outcrop (1 site). Thirty-one (46 percent) of the detected sites had a sandy type seafloor, 34 (50 percent) of the sites had a rubble and sand type seafloor, and three (4 percent) of the sites had rock outcroppings in the area. It must be emphasized that, because of the large differences between the positions of the objects detected by the demonstrator and the installed positions of the targets, it is not possible to be certain that the objects that were detected were actually on the type of seafloor observed for the installed targets.

For a comparison, the seafloor types (and percentage of each type) for all the target sites in the demonstration area of the range (193 targets) were: 115 sandy sites (59.6 percent); 73 rubble and sand sites (37.8 percent); and five sites with some type of rock outcropping (2.6 percent).

The following sections provide demonstration detection and classification results. The results are based on the Table 5-4 "Number Used for Assessment" column values and the data in Table D-4 for the detected objects.

**5.2.4.1 Critical Radius ($R_{crit}$).** Before the demonstrator's performance can be fully evaluated, an appropriate $R_{crit}$ (maximum radial distance that a prospect position can be away from a known target position for the detection to count) must be determined. The desired $R_{crit}$ for an actual UXO survey is the maximum sensor range of the system or systems that are used to relocate and identify the suspect UXO for possible cleanup. The UXO relocation system is unknown at this time. Therefore, an $R_{crit}$ was determined for the demonstration assessment effort based on the expected overall navigational accuracy of the demonstrator's equipment. The $R_{crit}$ will be used to calculate the detection ratios that are defined in Section 5.1 (Evaluation Scheme). To not limit the presentation of the assessment results to a single $R_{crit}$, tables of detection ratios versus a range of $R_{crit}$ values will be provided in later sections.

Factors that affect the determination of $R_{crit}$ if the primary sensor is a side-scan sonar and a USBL sub-surface navigation system is used are:

- Absolute navigational accuracy re: vessel position
- Relative navigational accuracy re: location of the towfish
- Relative navigational accuracy re: heading of the towfish
- Relative navigational accuracy re: range to target
- Sensor resolution along track
- Sensor resolution across track
- Display resolution along track
- Display resolution across track
- Redundancy of search

Typical values for the navigational errors are (all navigational errors are reported at 3$\sigma$ levels, i.e., 99 percent of observed errors are less than the reported value):

- Vessel Position, ±3 meter (based on differential GPS)
- Location of the towfish, 1.5 percent of slant range plus 3-degree bearing error or ±1.5-meter range error and ±5.25-meter bearing error at a slant range of 100 meters (based on a USBL acoustic navigation system)
- Location of target relative to towfish, 3 percent of slant range plus 1.5-degree bearing error or 3-meter range error and 2.75-meter bearing error (based on side-scan sonar system with heading sensor)

This results in a total navigation error budget of 11 meters. Since the demonstrators did not use a USBL acoustic navigation system or determine towfish heading, $R_{crit}$ should arguably be increased. The position of a target detected on a side-scan sonar is calculated from the detection range, heading of the side-scan sonar towfish, position of the side-scan sonar towfish, and position of the towing vessel. In the present survey, only the first was known with any accuracy. The remainder were estimated or assumed. The relative position of the towfish was estimated using the "layback" from the vessel. This assumes that the towfish has a horizontal displacement which can be estimated from the amount of tow cable deployed or "cable out." Depending upon the operator, the position of the towfish is projected this distance from the ship on either the reciprocal heading of the vessel or the reciprocal of the course-made-good. The use of course-made-good is preferable since it removes any "crab angle" associated with steering the vessel down the track line. Typically, for a shallow water survey such as this, these errors should be less than ±10 meters (total error on fish position 13 meters). Finally, the accuracy of the position of the target will be a function of the range to the target and any towfish "crab angle." This survey was done with a maximum range of between 100 and 150 meters. Therefore, we can determine the maximum effect of towfish crab angle. Figure 5-4 is a plot of error versus towfish crab angle (for a 100-meter slant range).

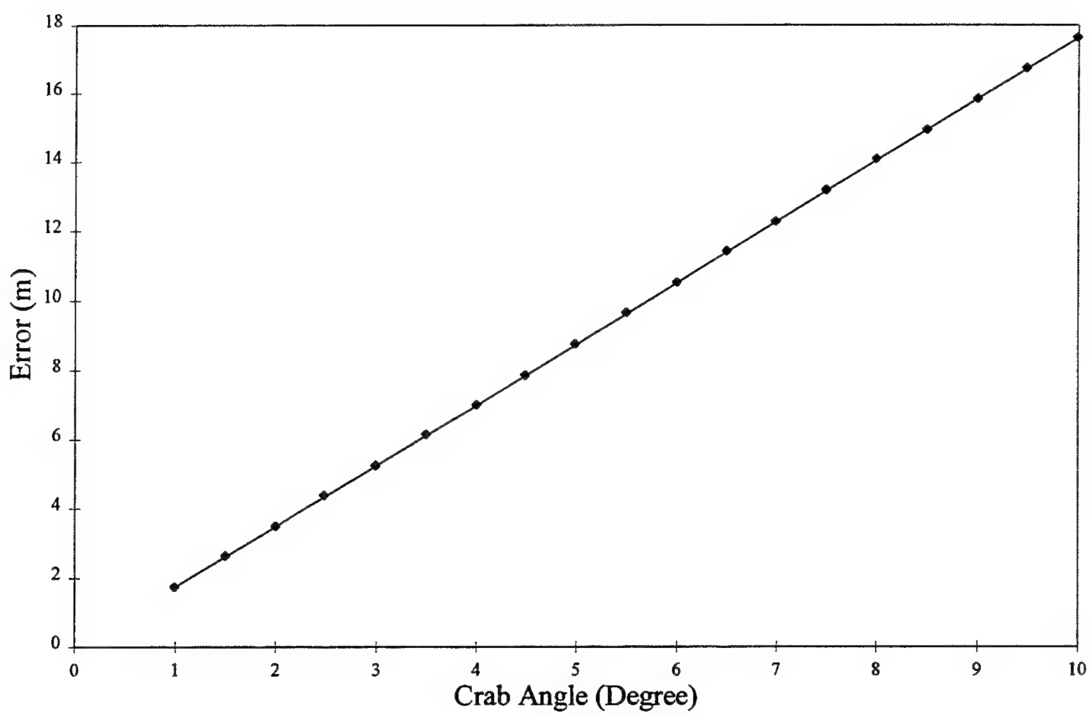


Figure 5-4. Towfish Crab Angle Error

If we assume a 3σ error of 10-degree towfish crab angle, the error will be 18 meters. The combined error would be 31 meters (total navigation error budget of 13 meters plus 18 meters for crab angle). Therefore, 31 meters was chosen as the primary $R_{crit}$ for the demonstration assessment. It should be noted that the contractor reported a position error with a mean value of 35.4 meters and standard deviation of 20 meters (1 σ, or 60 meter 3 σ) on the calibration range.

An $R_{crit}$ of 31 meters will be used to calculate a set of detection ratios for the demonstration. However, a figure showing detection ratios (percent detected) versus $R_{crit}$ will also be included in a section to follow. This will allow the reader to determine the detection ratio for various possible relocate sensors (having various $R_{crit}$'s). For example, it has been reported that Navy Explosive Ordnance Disposal (EOD) personnel typically search for (relocate) underwater UXO by performing seafloor circle searches using a 15-meter search line. The appropriate $R_{crit}$ for this exercise would be a value of 15 meters or less.

Seventeen objects were detected within an $R_{crit}$ of 31 meters. Figure 5-5 shows the area of the range (between the 10-meter and 50-meter seafloor contour lines), the installed target positions in the demonstration area, and the positions of the 17 objects detected within an $R_{crit}$ of 31 meters of the installed targets. Each "+" in the figure represents an installed target position, and each "o" represents an object detected.

**5.2.4.2. Data Set Variables.** Table 5-5 provides the baseline target set and calculated detection values for the demonstration ($R_{crit}$ value of 31 meters).

Table 5-6 gives the NFESC target as-installed information, the demonstrator's classification data, and the calculated distances between the actual installed positions and the positions reported by the demonstrators for the 17 targets detected within the $R_{crit}$ of 31 meters.

**5.2.4.3 Detection Ratios**. With the values given in Table 5-5, the detection ratios were calculated to be (detection ratios defined in Section 5.1, Evaluation Scheme):

| | | |
|---|---|---|
| Overall Detection Ratio ($DR_{all}$) | 17/145 | 11.7% |
| Ordnance Detection Ratio ($DR_{ord}$) | 12/111 | 10.8% |
| Non-Ordnance Detection Ratio ($DR_{non-ord}$) | 5/34 | 14.7% |
| Small Target Detection Ratio ($DR_{small}$) | 6/25 | 24% |
| Medium Target Detection Ratio ($DR_{med}$) | 7/94 | 7.4% |
| Large Target Detection Ratio ($DR_{large}$) | 4/26 | 15.4% |
| Buried Target Detection Ratio $DR_{buried}$) | 1/4 | 25% |

**(a) Overall Detection Ratio (17/145 or 11.7%).** The Overall Detection Ratio is a measure of the demonstrator's ability to detect all types of the baseline targets, regardless of the demonstrator's ability to correctly identify them.

**(b) Ordnance Detection Ratio (12/111 or 10.8%).** The Ordnance Detection Ratio is a measure of the demonstrator's ability to detect ordnance baseline targets, regardless of the demonstrator's ability to correctly identify them. The demonstrators in fact made no effort to distinguish between ordnance and non-ordnance objects.

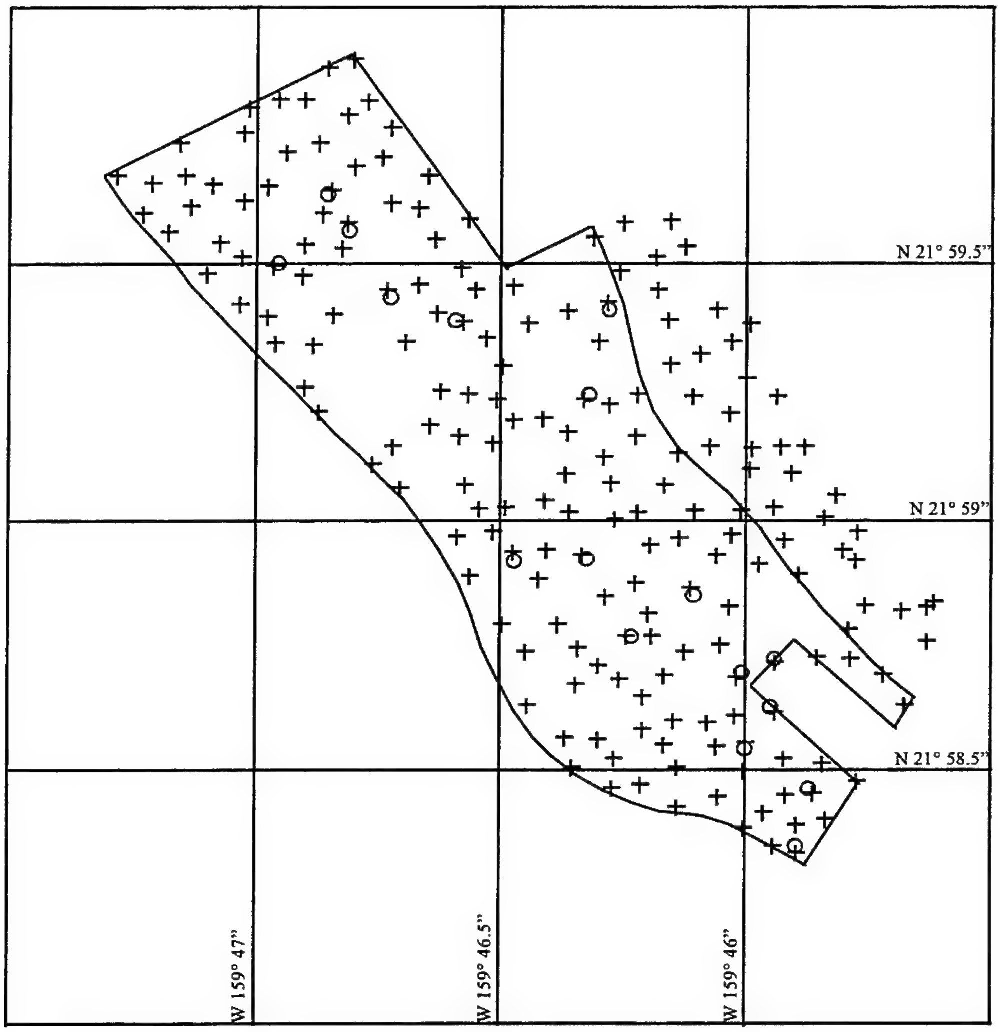


Figure 5-5. Detections for $R_{crit}$ of 31 Meters

Table 5-5. Data Set Variables - Baseline Target Set and Calculated Values Using an $R_{crit}$ of 31 Meters

| VARIABLE NAME | SYMBOL | VALUE |
|---|---|---|
| **Baseline Target Set** | BT = BO + BNO | 145 |
| Baseline Ordnance Set | BO | 111 |
| Baseline Non-Ordnance Set | BNO | 34 |
| Baseline Large Targets | BLT | 26 |
| Baseline Medium Targets | BMT | 94 |
| Baseline Small Targets | BST | 25 |
| Baseline Buried Targets | BBT | 4 |
| **Detected Target Set** | DT = DO + DNO | 17 |
| Detected Large Targets | DLT | 4 |
| Detected Medium Targets | DMT | 7 |
| Detected Small Targets | DST | 6 |
| Detected Buried Targets | DBT | 1 |
| Multiple Detected Targets | MDT | 0 |
| Detected Ordnance | DO = TP + FN | 12 |
| True Positives | TP | 12 * |
| False Negatives | FN | 0 * |
| Detected Non-Ordnance | DNO = TN + FP | 5 |
| True Negatives | TN | 0 * |
| False Positives | FP | 5 * |
| Falsely Detected Targets | FDT | 71 |
| Falsely Detected Ordnance | FDO | 71 |
| Falsely Detected Non-Ordnance | FDNO | 0 * |
| **Undetected Target Set** | UDT | 128 |
| Undetected Ordnance | UO | 99 |
| Undetected Non-Ordnance | UNO | 29 |

*The demonstrators did not attempt to distinguish between ordnance and non-ordnance. Therefore, these values have no significance.

Table 5-6. As-Installed and Detected Data for the 17 Targets Within $R_{crit}$ of 31 Meters

| SITE NAME | TARGET SHORT NAME | NFESC CLASS (size, weight) | WATER DEPTH (meters) | BURIAL DEPTH (meters) | SEAFLOOR TYPE (NFESC) | MMTC CLASS (size, weight) | POSITION ERROR (meters) |
|---|---|---|---|---|---|---|---|
| D001 | CART20M | Small, Light | 44.1 | | Smooth Sand | Medium, Medium (2) | 22.9 |
| D010 | AM_BOX | Large, Medium | 36.1 | | Sand Ripples | Medium, Medium (2) | 27.0 |
| D022 | 3SPIPE | Small, Light | 35.4 | | Sand Ripples | Medium, Medium (2) | 17.1 |
| D029 | ROCK5 | Medium, Medium | 30.9 | | Sand Ripples | Medium, Medium (2) | 23.7 |
| D034 | ROCK275 | Small, Light | 28.5 | | Sand Ripples | Medium, Medium (2) | 30.2 |
| D039 | MK106 | Medium, Light | 21.6 | | Sand Ripples | Medium, Light (3) | 15.0 |
| D047 | 2PROJ538 | Medium, Medium | 30.3 | | Rubble & Sand | Medium, Medium (2) | 19.8 |
| D059 | CART20M | Small, Light | 21.4 | | Sand Ripples | Medium, Medium (2) | 30.7 |
| D067 | MDRUM | Large, Medium | 26.7 | | Rubble & Sand | Buried | 18.6 |
| D068 | PROJ554 | Medium, Medium | 33.0 | | Rubble & Sand | Medium, Medium (2) | 29.5 |
| D113 | LCHAIN | Medium, Medium | 18.8 | 0.1016 | Sand Ripples | Large, Heavy (1) | 28.9 |
| D131 | CASE40M | Small, Light | 19.9 | | Rubble & Sand | Medium, Light (3) | 27.3 |
| D139 | 4SPIPE | Medium, Medium | 15.1 | | Sand Ripples | Medium, Light (3) | 20.5 |
| D141 | MK82 | Large, Heavy | 24.7 | | Rock Outcrop Flat | Medium, Medium (2) | 29.8 |
| D149 | 3MK106 | Medium, Light | 40.4 | | Rubble & Sand | Medium, Medium (2) | 24.4 |
| D160 | MK81 | Large, Heavy | 23.0 | | Sand Ripples | Medium, Medium (2) | 24.2 |
| D171 | ROCK275 | Small, Light | 23.3 | | Rubble & Sand | Medium, Medium (2) | 16.1 |

**(c) Non-Ordnance Detection Ratio (5/34 or 14.7%).** The Non-Ordnance Detection Ratio is a measure of the demonstrator's ability to detect non-ordnance baseline targets, regardless of the demonstrator's ability to correctly identify them.

**(d) Small Target Detection Ratio (6/25 or 24%).** The Small Target Detection Ratio is a measure of the demonstrator's ability to detect small targets, regardless of the demonstrator's ability to correctly identify them.

**(e) Medium Target Detection Ratio (7/94 or 7.4%).** The Medium Target Detection Ratio is a measure of the demonstrator's ability to detect medium targets, regardless of the demonstrator's ability to correctly identify them.

**(f) Large Target Detection Ratio (4/26 or 15.4%).** The Large Target Detection Ratio is a measure of the demonstrator's ability to detect large targets, regardless of the demonstrator's ability to correctly identify them.

**(g) Buried Target Detection Ratio (1/4 or 25%).** The Buried Target Detection Ratio is a measure of the demonstrator's ability to detect buried targets, regardless of the demonstrator's ability to correctly identify them. The one buried target detected was not identified by the demonstrators as buried, and one target that was not buried was identified as being buried.

**5.2.4.4 Ordnance Typing Ratios.** The Ordnance Typing Ratios describe the demonstrator's ability to distinguish between ordnance and non-ordnance objects, independent of the demonstrator's ability to detect the items. The following values were calculated for these ratios:

| | | |
|---|---|---|
| False Negative Ratio (FNR) | 0/12 | 0% |
| False Positive Ratio (FPR) | 5/5 | 100% |

**(a) False Negative Ratio (0/12 or 0%).** The False Negative Ratio is a measure of the demonstrator's ability to identify ordnance objects as ordnance, regardless of the demonstrator's ability to detect the ordnance. This ratio describes the probability that a demonstrator will report a detected ordnance object as non-ordnance and the object will go unremediated. The demonstrators were not able to distinguish between ordnance and non-ordnance. Therefore, this ratio has no significance.

**(b) False Positive Ratio (5/5 or 100%).** The False Positive Ratio is a measure of the demonstrator's ability to identify non-ordnance objects as non-ordnance, regardless of the demonstrator's ability to detect the non-ordnance objects. This ratio describes the probability that a demonstrator will report a detected non-ordnance object as ordnance and unnecessary effort will be expanded to remediate the object. Again, since the demonstrators were not able to distinguish between ordnance and non-ordnance, this ratio also has no significance.

**5.2.4.5 False Alarm Rate (76/88 or 86%).** The False Alarm Rate is a measure of the demonstrator's ability to distinguish ordnance-like items from any other target. It is dependent on the demonstrator's ability to detect the items because the Falsely Detected Ordnance is included. This measure describes the likelihood that a demonstrator will report false alarms and unnecessary effort will be expended to remediate the item. Because the demonstrator did not classify their detection by type, and because unknown target in-situ inspections were not performed, the FAR may be artificially high.

**5.2.4.6 Classification Ratios**. Classification Ratios describe the demonstrator's ability to distinguish between different classes of ordnance, independent of the demonstrator's ability to detect the targets. Classification Ratios were calculated for size (small, medium, and large) and weight (light, medium, and heavy) classes only. These were the only classifications attempted by the demonstrators. Classification ratios are determined by comparing the demonstrator's classification of the detected baseline target set with the actual classification of the detected baseline target set. The following classification ratios were calculated:

Size Classification Ratios

| | | |
|---|---|---|
| Small Target Classification Ratio ($CR_{small}$) | 0/6 | 0% |
| Medium Target Classification Ratio ($CR_{medium}$) | 6/7 | 85.7% |
| Large Target Classification Ratio ($CR_{large}$) | 0/4 | 0% |

Weight Classification Ratios

| | | |
|---|---|---|
| Light Target Classification Ratio ($CR_{light}$) | 2/7 | 28.6% |
| Medium Target Classification Ratio ($CR_{medium}$) | 4/7 | 57.1% |
| Heavy Target Classification Ratio ($CR_{heavy}$) | 0/2 | 0% |

In order to see how the detection ratios for the demonstration effort are effected by the $R_{crit}$, Figure 5-6 is provided.

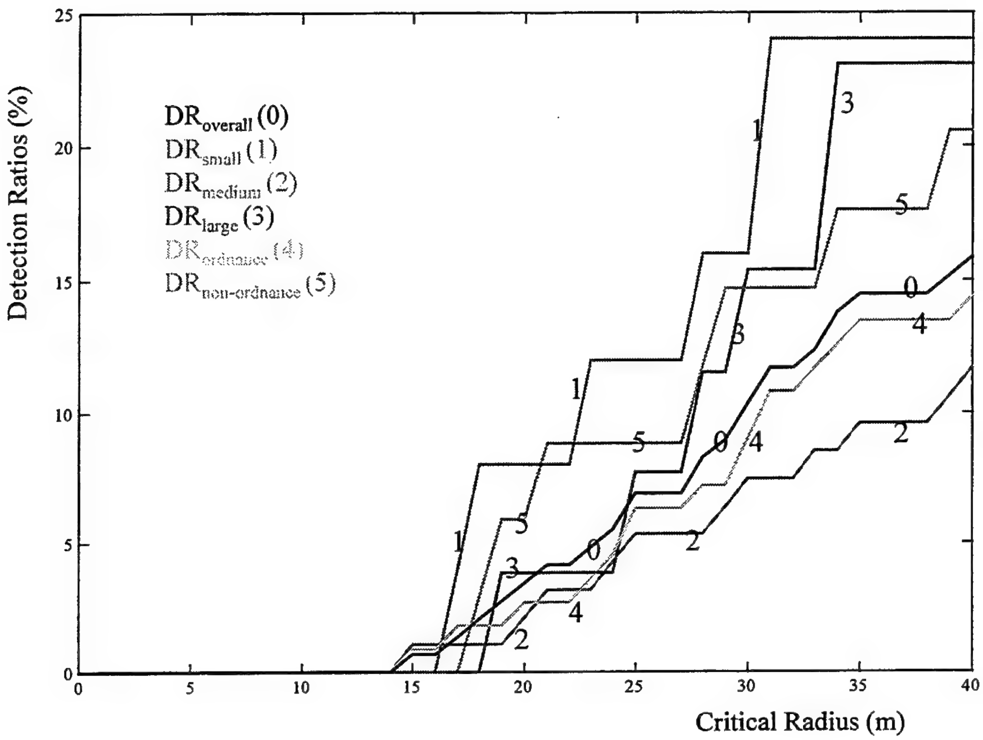


Figure 5-6. Detection Ratios Versus $R_{crit}$

**5.2.5 Comparison of Demonstrator's Detection Performance with Random Target Location Choices.** The detection ratio curve for large and medium targets in Figure 5-6 would be expected to be higher than for small targets, especially when a side-scan sonar is used as the primary means of target detection. This is not the case. In fact, the detection ratio curve for small targets is higher than for both large and medium targets. This situation, along with the extremely large reported navigation errors, suggests the possibility that the resulting detection ratios are based at least partly on the random probability that a detected (or falsely detected) target with a huge navigation error would end up within $R_{crit}$ of some (likely other) baseline target.

To provide insight to this question, we compared the overall detection ratio of the demonstrator's target set with the overall detection ratios of sets of target positions randomly selected within the surveyed area. The overall detection ratio versus $R_{crit}$ for the demonstrator's 88 reported targets is shown as $DR_{overall}$ in Figure 5-6. The overall detection ratios for 10 sets of 88 randomly selected target positions were computed. Each set of 88 random target positions was created with an algorithm which first chose a random northing between the northernmost and southernmost points of the surveyed area based on a uniform distribution. Using that northing, the easternmost and westernmost bounds of the surveyed area were then determined. Finally, a random easting was chosen between the easternmost and westernmost bounds of the surveyed area based on a uniform distribution. This process was repeated 88 times to select 88 random target positions in the surveyed area. Ten sets were created and plotted. The overall detection ratios versus $R_{crit}$ for each are shown in Figure 5-7.

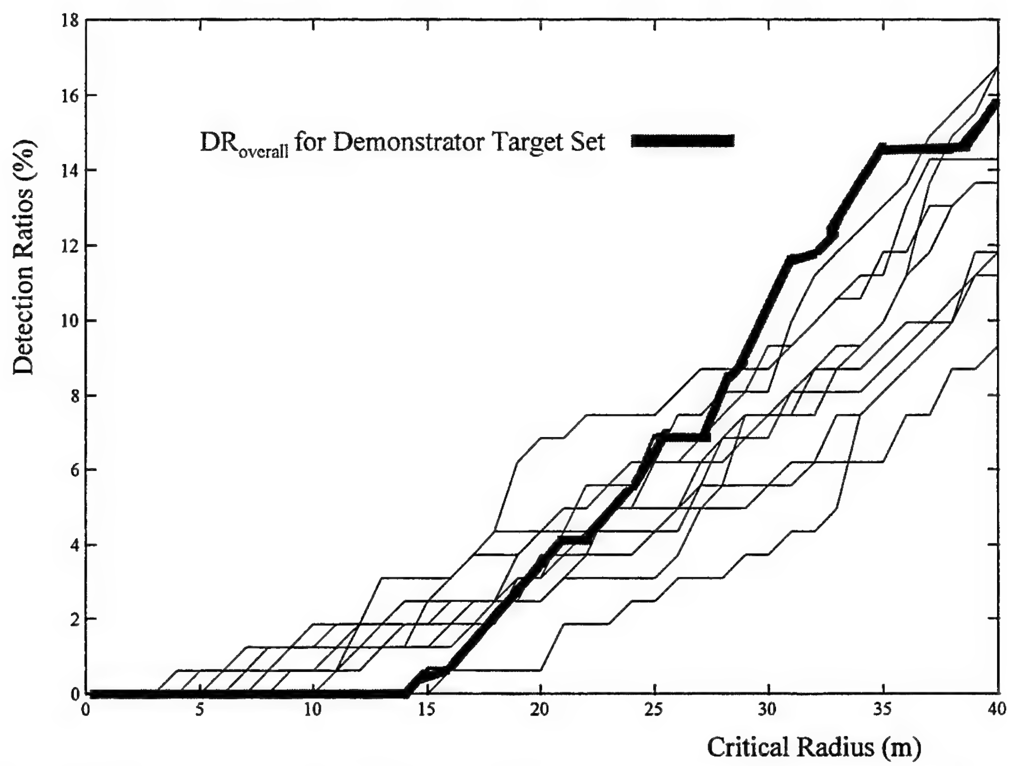


Figure 5-7. Demonstrator Overall Target Detection Ratio and Random Overall Target Detection Ratio Versus $R_{crit}$

A completely effective detection method would be expected to result in an abrupt step function in Detection Ratio at an $R_{crit}$ equal to the navigational accuracy of the detection system. On the other hand, a completely random choice of target locations would be expected to have a somewhat linear relationship between Detection Ratio and $R_{crit}$, as is shown in Figure 5-7. The slope of the demonstrator's Detection Ratio versus $R_{crit}$ is only slightly steeper than the general trend of random target choices. This analysis suggests that the demonstrator's performance is only slightly better than completely random target location choices.

**5.2.6 Conventionality of Demonstration Equipment, Offshore Operations, and Data Analysis**. Some modifications were made to the sensor systems used, survey operational procedures, and analysis of the data obtained for the demonstration. A brief discussion of these modifications is provided in Section 4.2.1 (Demonstration Sensor Systems). In general, the sensor systems were commercial state-of-practice. The side-scan sonar was a standard commercial unit. Its output was fed to a data collection and sonar signal processing system. The signal processing software was developmental, but based on a commercial product. There are a number of vendors of similar sonar signal processing software. The software was used to produce side-scan sonar mosaics, which is not necessarily done on a typical side-scan sonar survey. Both a prototype and a commercially available sound source were used with the seismic receiver system. The swath bathymetric system was a leased commercial system, with custom processing of the data within the data collection system. The vendor provides a data collection and processing capability and the hardware is compatible with a number of commercial data collection products. The software used for processing the AAHIS data was specially designed for detection and location of anomalous targets

Above is a brief assessment. NFESC does not currently have adequate information to fully analyze and provide an assessment of how conventional or "artsy" the reduction and interpretation of the data was. This aspect of the project work needs to be addressed and understood, especially if selected portions of the demonstration were to be repeated by another demonstrator. The demonstration team knows and understands their data collection and reduction techniques intimately, and is better suited to provide a discussion on this matter. NFESC has provided some discussion regarding a conventional side-scan sonar survey and navigation technologies (Section 5.2.1, Discussion of Demonstration Operational Approach and Problems Encountered). A detailed discussion regarding the conventionality of the demonstration equipment, data collection, and reduction approach and techniques is included in Appendix F.

In Appendix F, MMTC states "However, in spite of these problems, the data do suggest that the technique in general has significant potential." Based on the data, this conclusion is difficult to support. But with our experience using another brand of side-scan sonar, which used a generation older technology, we have been able to detect 0.10-inch diameter cables with a priori knowledge. With a priori knowledge, it was expected that only the smallest targets, the buried targets and those obscured by natural features, would not be detected with proper search

techniques. The planned concept of using the side-scan sonar and swath bathymetry to do a preliminary survey of the area followed by detailed investigation of targets using high resolution side-scan (short range), sub-bottom profiler, and a magnetic sensor to classify the targets should have resulted in a sufficiently higher overall score.

**5.2.7 MMTC Analysis with A Priori Knowledge of Target Positions.** Because of the large navigational errors in their data, MMTC undertook to re-analyze their data using the known target coordinates to compute the layback of the side-scan sonar fish. The determination of layback using known targets is a common side-scan sonar technique. Generally, the geodetic position of a target is not known so a set of reciprocal passes at the same target is the most common method of layback determination, using side-scan data. This is accomplished by identifying the same target on two reciprocal lines and determining the position of the towing vessel as the fish is abreast of the target. The distance between the two positions is twice the layback. The method used by MMTC is based on the assumption that any target they detected within 50 meters of the true position is likely one of the targets. For each survey line, they computed a "least squared" error estimate, using the known target positions as truth and any detected target within 50 meters as the detected target. They then adjusted the navigation for that line by the error estimate (using both the magnitude and direction of the error). The adjusted coordinates were then provided for 61 targets. Table 5-7 is the summary of their performance with a priori knowledge of the target positions.

Their overall detection ratio with navigation corrections based on a priori knowledge, at $R_{crit} = 31$ meters, is 20 percent. Figure 5-8 is a plot of detection ratio versus critical radius, with navigation corrections based on a priori knowledge.

### 5.3 Applying the Demonstration Results to a UXO Cleanup Scenario

This section will present a brief discussion of how results from STMC can be used to evaluate various technologies proposed for cleanup of offshore ordnance.

If this had been an actual UXO survey, MMTC would have detected and classified 88 potential UXO targets. The next phase of the operation would be to identify and dispose of UXO material. If, as suggested previously, the critical detection range ($R_{crit}$) has been set based on the capabilities of the UXO identification system to be used for cleanup, the procedure will be:

- Deploy the identification system at the detection coordinates and search a circular area with a radius of $R_{crit}$, identifying all targets within the area, i.e., do a complete search of the area. This will guarantee that, even if the detection was a false target, no UXO exists within $R_{crit}$.
- Render safe any UXO.
- Dispose of any UXO-like material (it is assumed that any ordnance-like material identified will be disposed of to preclude any possibility of future incidents based on an ordnance-like object being found).

If we assume that the identification system is 100 percent efficient, we can then rate the survey and classification system based upon the overall cleanup effort. This rating would be based on a set of metrics which assesses the overall cost and efficiency of the process. A possible set of metrics for this would be the cost per item removed and the percent UXO cleaned up. This set of metrics will favor those systems that have the most efficient classification ability.

Table 5-7. Data Set Variables - Baseline Target Set and Calculated Values Using an $R_{crit}$ of 31 Meters with Corrected Navigation Data Based on A Priori Knowledge

| VARIABLE NAME | SYMBOL | VALUE |
|---|---|---|
| **Baseline Target Set** | BT = BO + BNO | 145 |
| Baseline Ordnance Set | BO | 111 |
| Baseline Non-Ordnance Set | BNO | 34 |
| Baseline Large Targets | BLT | 26 |
| Baseline Medium Targets | BMT | 94 |
| Baseline Small Targets | BST | 25 |
| Baseline Buried Targets | BBT | 4 |
| **Detected Target Set** | DT = DO + DNO | 29 |
| Detected Large Targets | DLT | 7 |
| Detected Medium Targets | DMT | 16 |
| Detected Small Targets | DST | 6 |
| Detected Buried Targets | DBT | 0 |
| Multiple Detected Targets | MDT | 4 |
| Detected Ordnance | DO = TP + FN | 23 |
| True Positives | TP | 23* |
| False Negatives | FN | 0* |
| Detected Non-Ordnance | DNO = TN + FP | 6 |
| True Negatives | TN | 0* |
| False Positives | FP | 6* |
| Falsely Detected Targets | FDT | 54 |
| Falsely Detected Ordnance | FDO | 54 |
| Falsely Detected Non-Ordnance | FDNO | 0* |
| **Undetected Target Set** | UDT | 116 |
| Undetected Ordnance | UO | 88 |
| Undetected Non-Ordnance | UNO | 28 |

*The demonstrators did not attempt to distinguish between ordnance and non-ordnance. Therefore, these values have no significance.

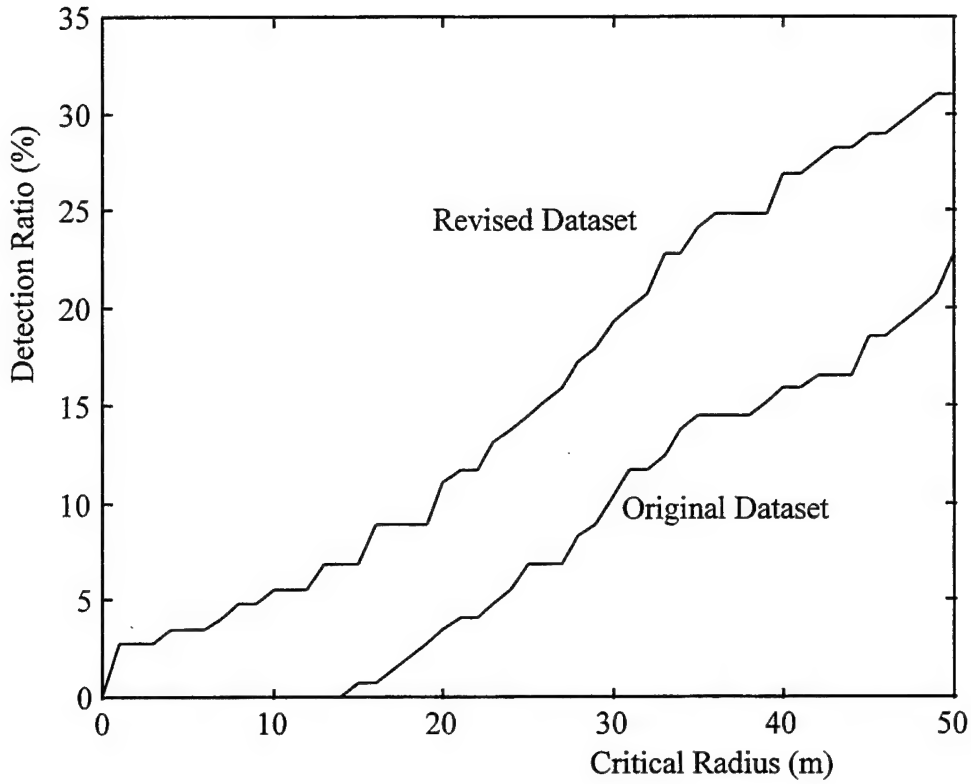


Figure 5-8. Detection Ratio Versus Critical Radius

For the purposes of this discussion, the cost per item removed will include the survey/classify and identify, but not the removal cost. This assumes that the survey/classify and identify cost can be quantified by a "day rate," while the rendering safe and disposal cost will vary depending upon the item. Thus, a system that does a very good search/classify but takes four times as much time may not score as well as a system that classifies more targets to be investigated, but the cost of the extra identifications is less than the cost of the extra search/classification.

Because of the large $R_{crit}$ involved in the MMTC results, we will assume that divers (using three divers spaced 2 meters apart, each searching 1 meter either side of his track) and a circling line are used as the identification system. For purposes of this estimate, we will assume 1 hour elapsed time per target identification. This would involve a 6 person dive team (3 divers, a dive supervisor, a standby diver, and a small boat operator). Using $60 per man-hour, the cost of identification would be $360 per item. To identify the 88 targets classified by the MMTC would have cost $31,680. The MMTC cost of the survey/classify phase was $350,000 (grant cost minus costs for AAHIS). Thus, the cost for each of the 12 ordnance items identified for removal

would have been $31,806 with a 10.8 percent removal rate (ordnance detection ratio computed for MMTC).

This metric could provide a means of computing the incremental cost of improvements between competing technologies demonstrated during future range testing.

To demonstrate this, the calculation for MMTC target set with a priori knowledge has a cost per item based on a survey/classify cost ($350,000) plus the same identify cost ($31,680) divided by the number of UXO items recovered (23), or $16,594 with a 20 percent removal rate. In this case, the revised data would clearly be the better of the two systems.

## 6.0 Conclusions

6.1 The demonstration evaluation/validation of potential underwater ordnance mapping and classification technologies is needed so that contaminated underwater sites can be made safe for public use.

6.2 The range described herein provided a controlled site suitable for evaluating ordnance location and classification methods. While the target mix is representative of ordnance that may be found at formerly used defense sites under U.S. responsibility, to be complete the mix should include mines and other hazardous material targets.

6.3 The PMRF, Barking Sands, Kauai, site offered a secure area with good support, water visibility (helpful for target installation and recovery operations), and a challenging test environment including varying seafloor bottom types and a seafloor with interesting magnetic properties. However, the often intense wave action and large amount of sediment transport that can be experienced at this site placed the test targets at the risk of being lost, especially targets in water depths less then 30 meters. Because of the high sediment transfer, the Barking Sands site is not suitable for a permanent range installation.

6.4 Design and layout of the range, and the techniques and hardware that were used to install and recover the targets, met the objectives and were successfully completed as planned. However, installation and recovery operations are labor and asset intensive and thus should be utilized only when permanent range facilities are not available.

6.5 The results of the ordnance mapping and classification demonstration conducted on the range by MMTC using the MMTC geophysical sensing systems were inconclusive because of problems encountered with system failures, navigation problems with location of towed sensors relative to survey vessel, and techniques.

6.6 The question of whether side-scan sonar and seismic exploration systems used for mineral exploration are acceptable for detecting underwater UXO can not be confirmed or denied with the data gathered in the demonstration. Despite the extremely low overall detection rations, the operational problems experienced by the demonstration team prevented a conclusive assessment of the applicability of these technologies.

6.7 The performance of magnetic and electromagnetic techniques for detecting underwater UXO in the high magnetic background environment could not be evaluated since the demonstration team was not able to operate these sensors on the range.

6.8 Since there was no independent range tracking of the user's vessel and sensors, identification of the Falsely Detected Targets must be done with the navigation data supplied by the demonstrator. If these data are not available, or not accurate, it is not possible to identify the Falsely Detected Targets.

6.9 The only attempt to detect targets in depths less than 10 meters was with the airborne hyper-spectral imaging system. However, due to various problems that occurred, this effort was not successful in detecting any targets. Locating ordnance in shallow water is most important, yet based on the results of the systems demonstrated, it is also the most difficult to accomplish.

## 7. Recommendations

7.1 Since the capability to satisfactorily detect and classify underwater ordnance has not been demonstrated, it is recommended that a permanent test range be established at a suitable site and that further technology demonstrations be conducted.

7.2 To reduce the costs associated with a future technology demonstration, it is recommended that a permanent classification and mapping range be established. A permanent range would provide for uniform comparison of competing survey technologies. The portable range demonstrated herein should be made available to used when cleanup site conditions are unique and cannot be duplicated by a permanent range. For example, a special site condition may be the need to demonstrate technology in an area with a high magnetic background signature or at a freshwater location.

7.3 Future testing should be conducted at a site with less severe wave and sediment transport conditions so that targets can be left in place longer without concern for target loss due to shifting sands.

7.4 On future ranges where shifting sediments and surf are present, it is recommended that shallow water targets (less than 10 meters water depth) be installed immediately prior to the start of demonstration operations, and recovered following the completion of the demonstration.

7.5 Demonstration tests should only be started when all required instrumentation and sensors have been shown to be fully functional. All surface/subsurface navigation, together with attendant demonstration sensor systems, should be thoroughly checked out and functioning as a system prior to conducting range demonstrations.

7.6 Future underwater ranges should include the target mix used herein and be supplemented with mines and other targets such as 55-gallon drums of simulated hazardous materials.

7.7 Future ranges should be equipped with control objects that are highly visible to sensors (for example, relatively large, metallic, highly reflective shapes, located at precisely known positions). Control points both in the calibration and demonstration areas would provide the demonstrator with a means of rapidly verifying their system performance at any time while operating on the range.

7.8 The demonstration team should have a full set of spares and backup systems "on board" for the sensor equipment that will be evaluated. This also applies to the navigation and tracking systems.

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## APPENDIX A

## POINTS OF CONTACT

Table A-1 contains a list of the primary points of contact for the Classification and Mapping of Underwater UXO project work. Table A-2 contains the mailing addresses for each of the points of contact and the full command/company name of each (acronyms or abbreviations are used in Table A-1).

Table A-1. Classification and Mapping of Underwater UXO Points of Contact

| PROJECT ASSOCIATION | NAME | COMMAND/ COMPANY | PHONE NUMBER | FAX NUMBER | E-MAIL ADDRESS |
|---|---|---|---|---|---|
| Project Leader | Black, Stan | NFESC | (805) 982-1002 | (805) 982-5204 | sblack@nfesc.navy.mil |
| Principal Investigator | Wicklund, David D. | NFESC | (805) 982-1191 | (805) 982-5204 | dwicklu@nfesc.navy.mil |
| Proposal for Project/ Division Director | Atturio, Mike | NFESC | (805) 982-1001 | (805) 982-5204 | matturi@nfesc.navy.mil |
| Proposal for Project/ Demo. Evaluations | Miller, Jim | NFESC | (805) 982-1169 | (805) 982-5204 | jmiller@nfesc.navy.mil |
| Obtained Environ. Permits | Kingsbury, Marcia | NFESC | (805) 982-1420 | (805) 982-5204 | mkingsb@nfesc.navy.mil |
| Project Financial Assistant | Pierpoint, Michele | NFESC | (805) 982-5391 | (805) 982-5204 | mpierpo@nfesc.navy.mil |
| Demonstration Team Leader | Morgan, Charles (Dr.) | MMTC/OBD | (808) 522-5611 | (808) 522-5618 | sauchai@aol.com |
| Demonstration Data Analysis/Seismic | Lockart, Doug | MMTC/CSD | (601) 232-7320 | (601) 232-5625 | dll@mmri.olemiss.edu |
| Demonstration Data Analysis | Reed, Tom (Dr.) | OIC | (808) 539-3708 | (808) 539-3710 | reed@kiawe.soest.hawaii. edu |
| Demonstration Imaging System | Mooradian, Greg (Dr.) | SETS Tech., Inc. | (808) 625-5262 | (808) 625-2474 | greg@groucho.sets.hawaii. com |
| Demonstration Chirp Sub-Bottom | Rocheleau, Robert | Sea Engineering Company | (808) 259-7966 | (808) 259-8143 | Not available at this time |
| Site Use/Support Lead | Burley, Stewart | PMRF | (808) 335-4231 | (808) 335-4331 | sburey@pmrf.navy.mil |
| Site Use/Field Support | Nishina, Vince | PMRF | (808) 335-4675 | (808) 335-4484 | vnishin@pmrf.navy.mil |
| Site Use/Support Environ. | Anderson, David | PMRF | (808) 335-4823 | (808) 335-4683 | danders@pmrf.navy.mil |
| Explosive Ordnance Disposal | Pedersen, Andy | NAVEODTECDIV | (301) 743-6852 | (301) 743-6947 | pedersen.eodtc@eodmgate .navsea.navy.mil |
| Explosive Ordnance Disposal | Paulus, Steven (LT) | EODMU3 | (805) 989-8009 | (805) 989-3876 | spaulus@pmo71.navy.mil |
| Navigation Specialist | Cannon, Stewart | Pelagos Corp. | (619) 292-8922 | (805) 292-5308 | 102140.2412@compuserve. com |
| Vessel Support | Seil, Mitchell | American Workboats | (808) 545-5190 | (808) 538-1703 | Not available at this time |

The following is a brief description of the major participants involved with the 1995 STMC Range activities, and a brief description of the responsibilities of each.

**Naval Facilities Engineering Service Center (NFESC), Port Hueneme, CA**. NFESC had responsibility for the overall project, including the final STMC range report. NFESC was directly responsible for control of the targets (inert ordnance and non-ordnance), design and establishment of the range, navigation instrumentation and logistics support to MMTC during the demonstration operations, demonstration evaluation, and range dis-establishment by target recoveries.

**Pacific Missile Range Facility (PMRF), Barking Sands, Kauai, HI**. PMRF is the Barking Sands Range operator. All STMC range operations were conducted within the PMRF Barking Sands Range perimeter. PMRF provided on-site support to NFESC during STMC preparation work and while STMC operations were in progress. NFESC maintained close contact with PMRF during the project operations. Permission was obtained from PMRF on a daily basis for project vessels and aircraft to enter and work in Barking Sands controlled range waters and airspace.

**Marine Minerals Technology Center, Ocean Basins Division (MMTC/OBD), Honolulu, HI**. MMTC/OBD was tasked by NFESC, via an Office of Naval Research (ONR) grant to the University of Hawaii at Manoa, to manage the demonstration effort and submit all deliverables to NFESC. MMTC/OBD also operated the NFESC surface and subsurface navigation systems, operated the NFESC integrated navigation system, and provided and operated a sidescan sonar system, and a bathymetric mapping system. The MMTC/OBD director of operations interfaced directly with the NFESC project principal investigator during the STMC project preparation, offshore operations, and reporting.

**Ocean Imaging Consultants (OIC), Honolulu, HI**. OIC is an independent consulting firm located at the Manoa Innovation Center in Honolulu, Hawaii. OIC subcontracted directly with MMTC/OBD. OIC was responsible for participating in the at-sea operations, integrating all data products from the operations, and generating the primary target location and classification predictions. OIC reported directly to MMTC/OBD during the project work.

**The Marine Minerals Technology Center, Continental Shelf Division (MMTC/CSD), University, MS**. MMTC/CSD is the affiliated academic research center with MMTC/OBD, and is located at the University of Mississippi. MMTC/CSD subcontracted directly with MMTC/OBD. MMTC/CSD provided a sub-seafloor reflection profiling system for the demonstration work. MMTC/CSD was also responsible for optimizing the integration of the navigation and sub-seafloor data into the demonstration analysis. MMTC/CSD reported directly to MMTC/OBD.

**SETS Technology, Inc., Mililani, HI.** SETS Technology provided, operated, and reported demonstration results from the Advanced Airborne Hyperspectral Imaging System (AAHIS). SETS Technology developed processing software which is specifically designed for detection and location of anomalous targets. This software was employed in the STMC project. SETS Technology reported directly to MMTC/OBD regarding all STMC project work.

**Pelagos Corporation, San Diego, CA.** Pelagos Corporation was under contract to NFESC to provide navigation support during target installation operations. The navigation support included target pre-plot positions, integration and offshore operation of navigation instrumentation, target as-installed plot of positions, and a report of the navigation effort. The final report by Pelagos gave an estimate of target position accuracy's. NFESC operated the navigation instruments during the target recovery operations. Pelagos reported directly to NFESC during all phases of the STMC project work that Pelagos was involved with.

**American Workboats, Honolulu, HI.** American Workboats supported the STMC project with the 30-meter Motor Vessel (M/V) American Islander and vessel crew. This support was provided to NFESC via a Military Sealift Command (MSC) contract. The M/V American Islander was utilized as the primary project support vessel during all phases of the project. MMTC/OBD obtained the services of the vessel for the demonstration effort through an independent contract. During the NFESC portions of the project work, American Marine Services interfaced directly with NFESC. Vessel mobilization and demobilization was also supported by American Marine Services, and took place at the American Marine Services facility in Honolulu, HI.

**Naval Airlift Organization (NALO), New Orleans, LA.** NALO scheduled all aircraft used to transport NFESC project hardware from Point Mugu, CA to Hickam Air Force Base, Honolulu, HI, and return. Navy Squadron VR-55 aircraft were the primary transporters of the equipment. Squadron VR-55 is stationed at Moffett Federal Airfield, Mountain View, CA. Funding was not required for the transportation of the hardware.

**Naval Weapons Station, Seal Beach, CA.** The Naval Weapons Station, Seal Beach provided all inert ordnance to the STMC project. This facility verified and certified that all of the inert ordnance was indeed inert prior to delivery to NFESC.

**Federal Industrial Supply Center (FISC), Pear Harbor, HI.** FISC, Pearl Harbor supplied the required trucks, forklifts, and personnel to offload the VR-55 aircraft and transport the NFESC project hardware from Hickam AFB to the American Workboats facility in preparation for vessel mobilization. FISC also transported the equipment from the American Workboats facility back to Hickam Air Force Base after completion of the STMC activities, and loaded the VR-55 aircraft for return transit to California. U.S. Army equipment and personnel were utilized for this effort. No funding was required for these services.

Table A-2. Mailing Addresses for Classification and Mapping of Underwater UXO Points of Contact

| COMMAND/ COMPANY | FULL NAME OF COMMAND/ COMPANY | MAILING ADDRESS |
|---|---|---|
| NFESC | Naval Facilities Engineering Service Center | Commanding Officer, NFESC (Code ESC51), 1100 23RD Ave., Port Hueneme, CA 93043-4370 |
| MMTC/OBD | Marine Mineral Technology Center, Ocean Basins Division | University of Hawaii, Look Laboratory, 811 Olomehani St., Honolulu, HI 96813-5513 |
| MMTC/CSD | Marine Mineral Technology Center, Continental Shelf Division | University of Mississippi, 220 Old Chemistry Building, University, MS 38677 |
| OIC | Oceanic Imaging Consultants | Manoa Innovation Center, 2800 Woodlawn Dr., #150, Honolulu, HI 96822 |
| SETS Tech., Inc. | SETS Technology, Inc. | 300 Kahelu Ave., Suite #10, Mililani, Hi, 96789-3911 |
| Sea Engineering Company | Sea Engineering Company | Makai Pier, Waimanalo, HI 96795 |
| PMRF | Pacific Missile Range Facility | Commanding Officer, PMRF, Barking Sands, Kakaha, Kauai, HI 96752-0128 |
| NAVEODTECDIV | Naval Explosive Ordnance Disposal Technology Division | Commanding Officer, NAVEODTECDIV, 2008 Stump Neck Rd., Indian Head, MD 20640-5070 |
| EODMU3 | Explosive Ordnance Disposal Mobile Unit Three | Officer in Charge, EODMU3, Naval Air Weapons Station, Point Mugu, CA 93042-5001 |
| Pelagos Corporation | Pelagos Corporation | 5434 Ruffin Rd., San Diego, CA 92123 |
| American Workboats | American Workboats | 65 N. Nimitz Highway, Pier 14, Honolulu, HI 96817 |

# APPENDIX B

## EXAMPLES OF THE SEAFLOOR CONDITIONS OBSERVED IN THE UXO CLASSIFICATION AND MAPPING UNDERWATER RANGE (SEAFLOOR ENVIRONMENT)

## AND

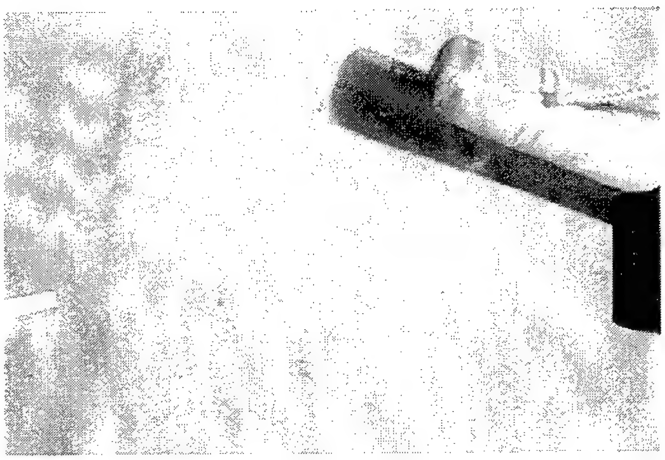
## SEAFLOOR CONDITIONS MATCHED WITH INDIVIDUAL TARGETS INSTALLED IN THE RANGE

# EXAMPLES OF THE SEAFLOOR CONDITIONS OBSERVED IN THE UXO CLASSIFICATION AND MAPPING UNDERWATER RANGE (SEAFLOOR ENVIRONMENT)

## B-1 Seafloor Environment

Images representing all of the seafloor environment types observed in the range are presented on the following two pages. A description of the seafloor type shown in each image is included beneath the image. The printed images were produced from video capture and scanned 35-mm slide film files.

# Seafloor Environment



Smooth Sand (SS)

Sand Waves (SW)

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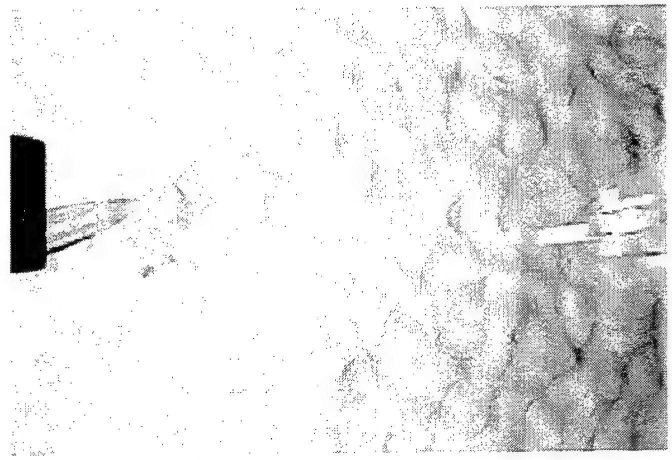
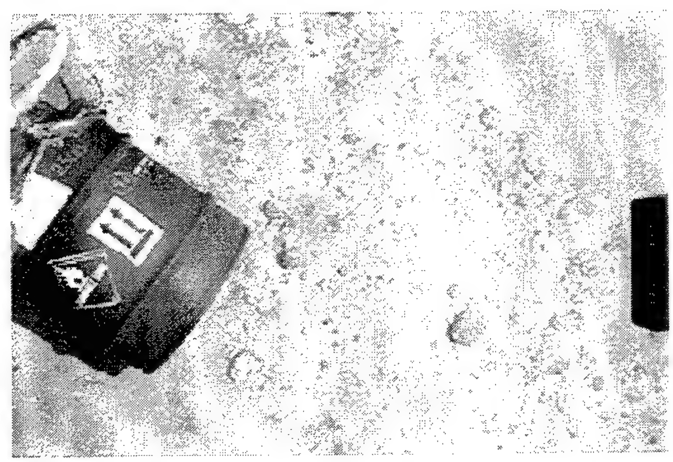
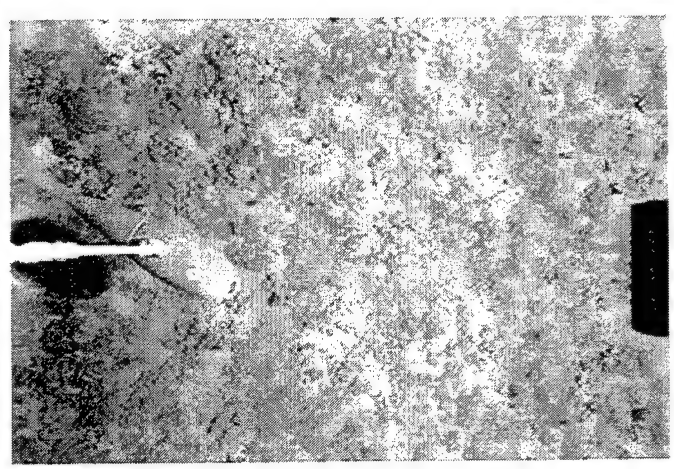


Sand Ripples (SR)



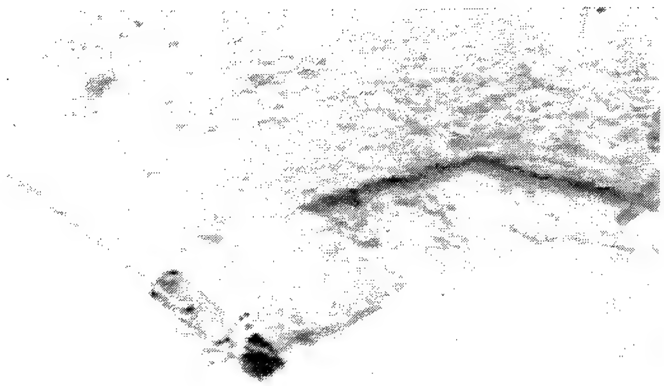
Rubble & Sand (R+S)



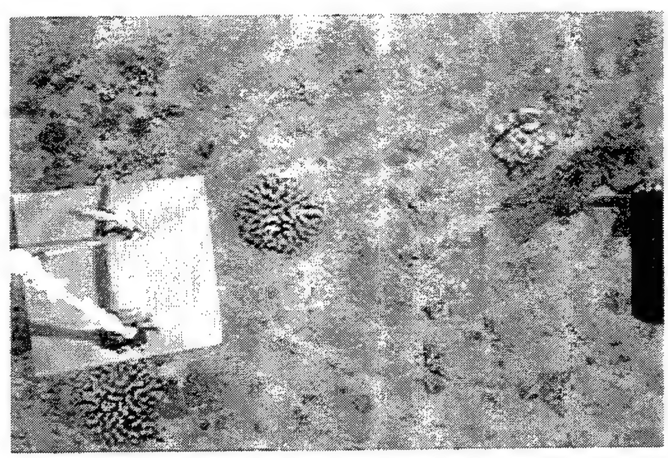
Rubble & Sand with Algae (RSA)

# Seafloor Environment

Ridge (RID)

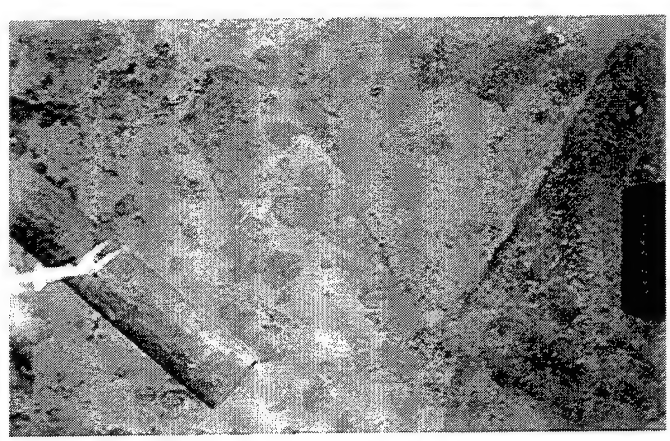


Rock Outcrop Shaped (ROS)



Coral (C)

Cave (CAVE)



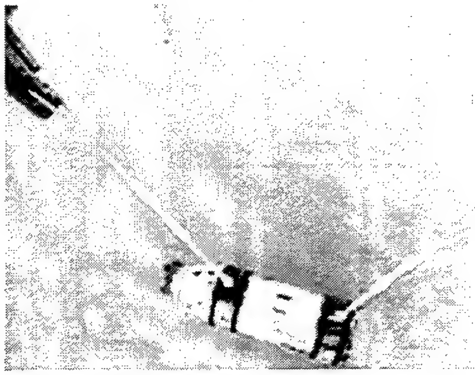
Rock Outcrop Flat (ROF)

## SEAFLOOR CONDITIONS MATCHED WITH INDIVIDUAL TARGETS INSTALLED IN THE RANGE

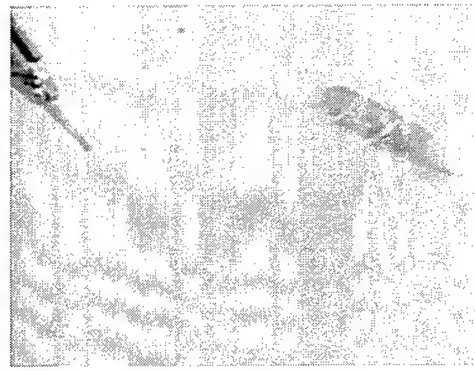
### B-2 Target Cell Seafloor Environments

The seafloor conditions observed in each target cell (area surrounding each target site) are shown in images that were collected during target installation operations. The images were taken immediately prior to or after the target of interest was installed. The printed images were produced from video capture and scanned 35-mm slide film files. The abbreviations for the seafloor type (i.e., SS) were defined in the previous section of this Appendix. Each image has one or more target sites assigned to it. If multiple sites are assigned to a particular image, the seafloor condition at each of the sites is nearly identical. Multiple sites with similar seafloor conditions were grouped to save space. The site identifiers can be referenced in the database example tables (Appendix D) to obtain additional information regarding the target at that site.

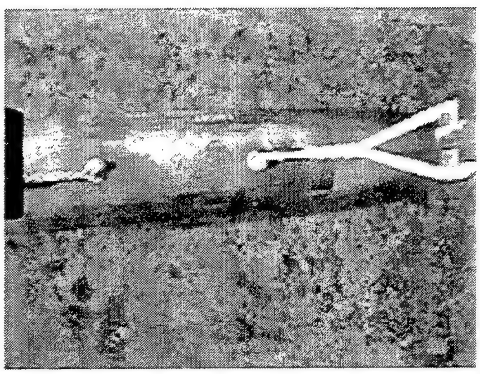
# Target Cells - Calibration Range



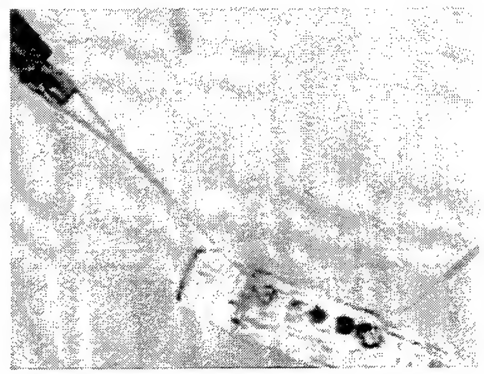
Site C4:SR (FRAG BOMB), C1, C2, C3:SR (TYP)



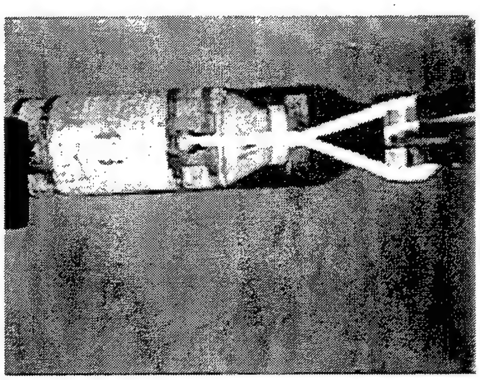
Site C5:SS (MK81)



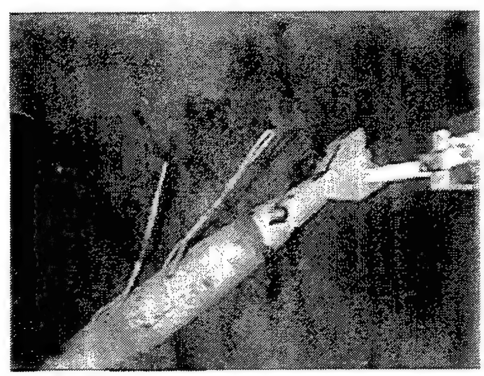
Site C6:RSA (MK81)



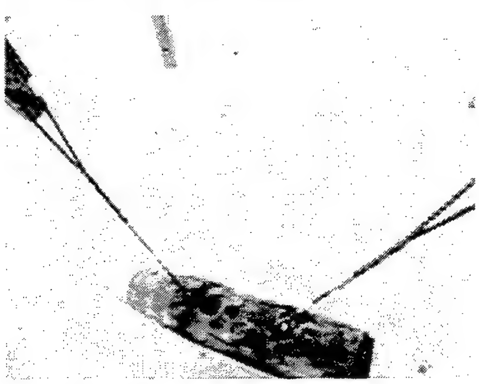
Site C7:SR (MK81)



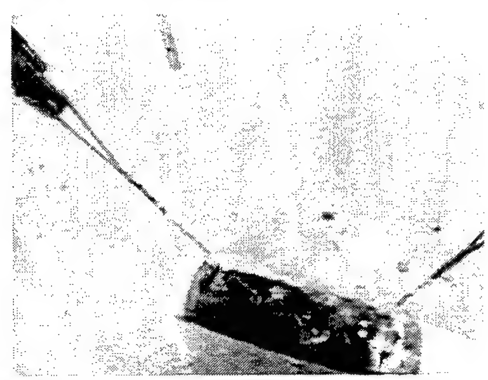
Site C8:SR (FRAG BOMB)



Site C9:SS (MK82)



Site C10:SS (MK81)



Site C11:SS (MK81)

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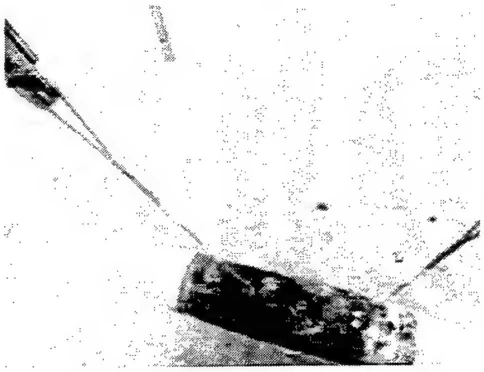
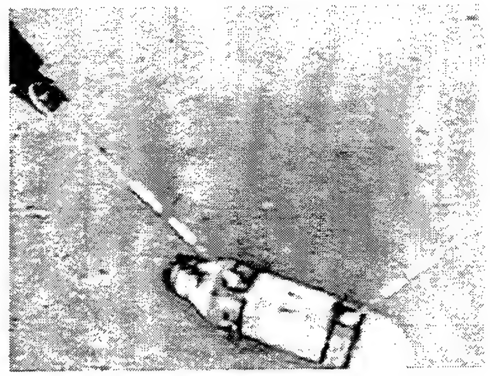
# Target Cells - Calibration Range

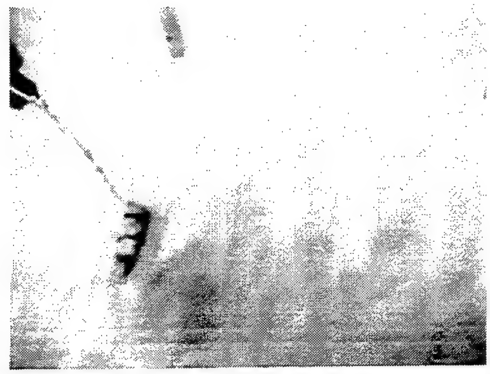


Site C11:SS (MK81)

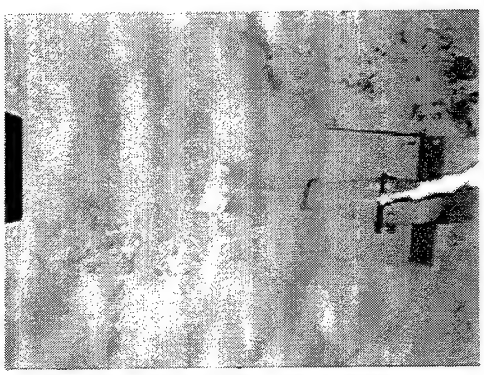


Site C12:SS (FRAG BOMB)

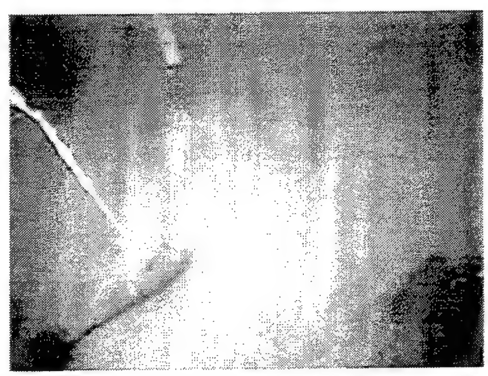
Site C15:SS (MK76), C13, C14:SS (TYP)



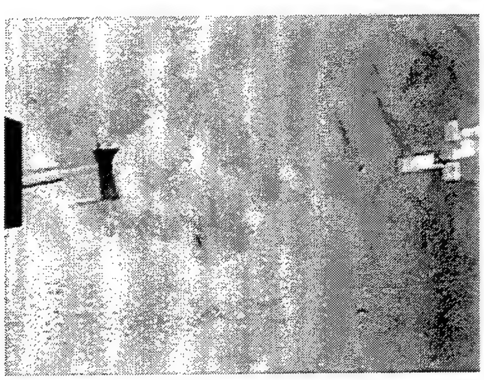
Site C16:SS (3MK106), C17 (TYP)



Site C18:R+S (MK76), C19 (TYP)



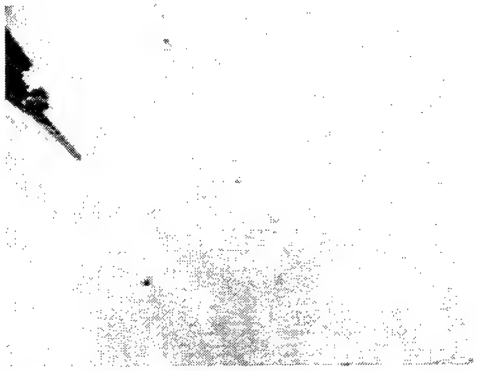
Site C20:SR (MK76)



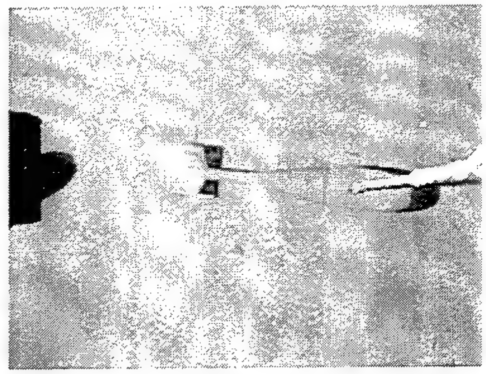
Site C21:SR (MK76)

Site C22:SR (MK106)

# Target Cells - Calibration Range

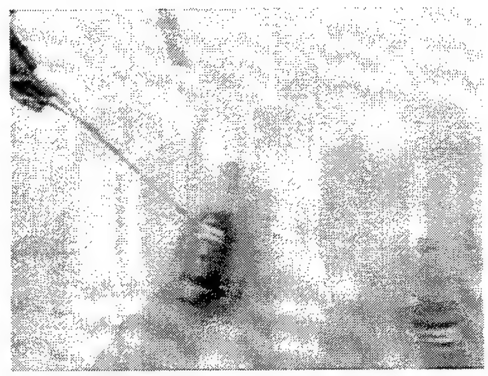


Site C23:SS (MK76)

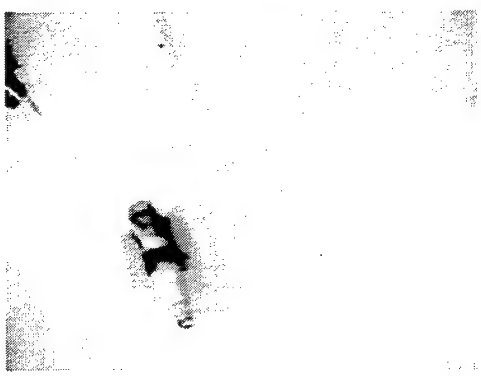


Site C24:SS (MK76), C25+C26 (TYP)

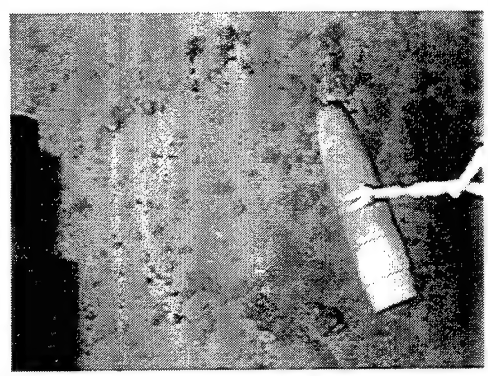
Site C27:SS (PROJ538)



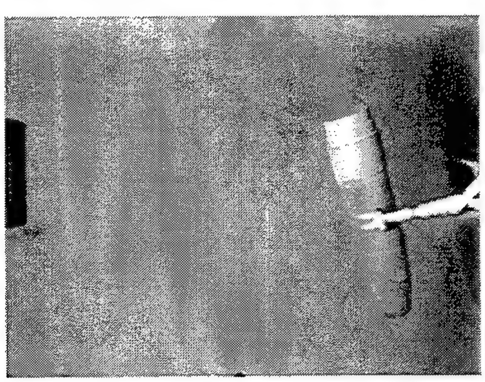
Site C28:SW (PROJ554)



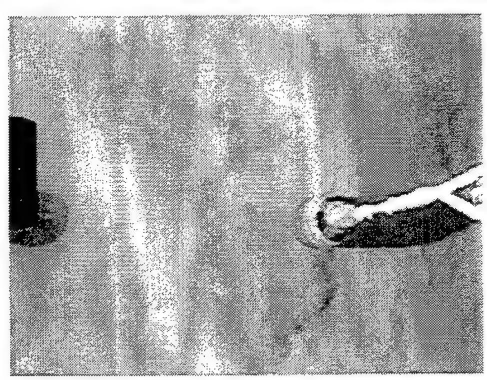
Site C29:SS (PROJ554)



Site C30:R+S (PROJ538)

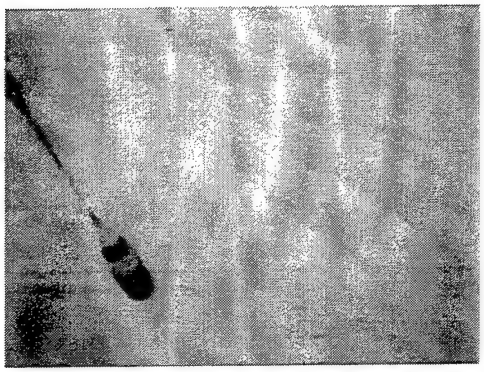


Site C31:SR (ROCK5)

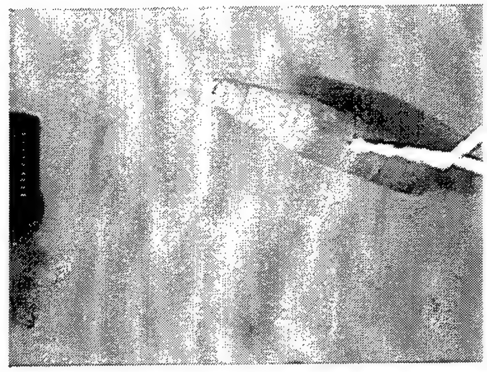


Site C32:SR (PROJ538)

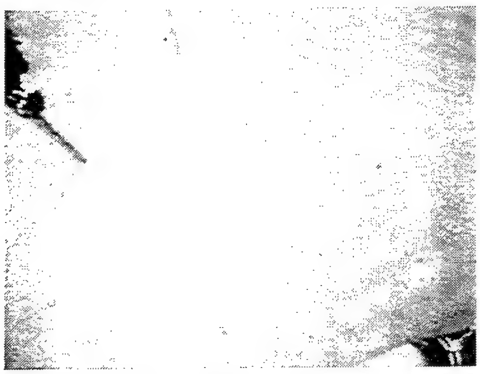
# Target Cells - Calibration Range



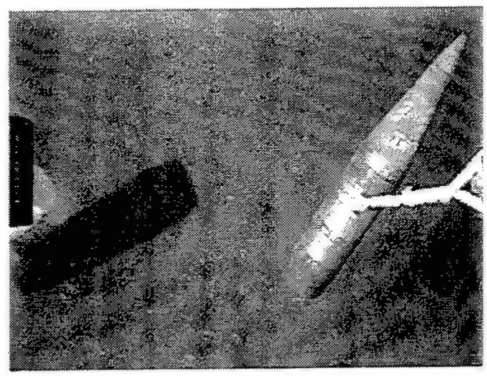
Site C33:SW (PROJ538)



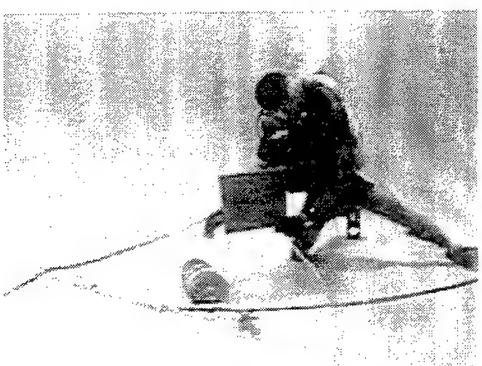
Site C34:SS (PROJ538)



Site C35:SS (PROJ554)



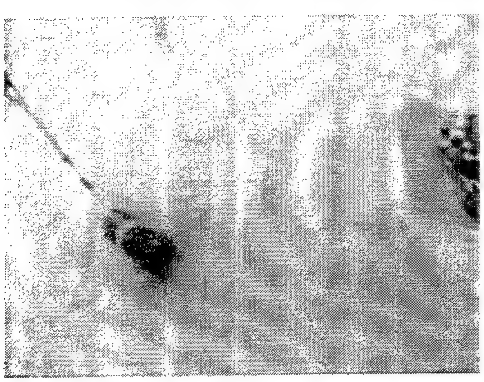
Site C36:SS (PROJ554)



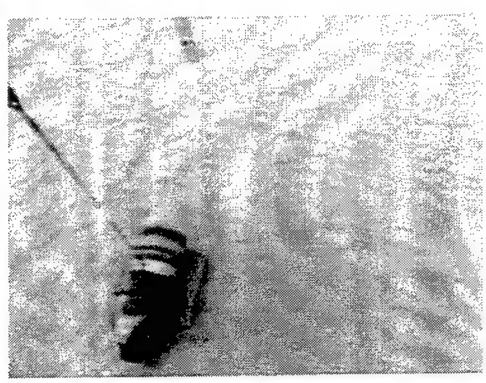
Site C39:SR (ROCK7), C37+C38 (TYP)

TARGET
RECOVERED
PRIOR TO TEST

Site C40:

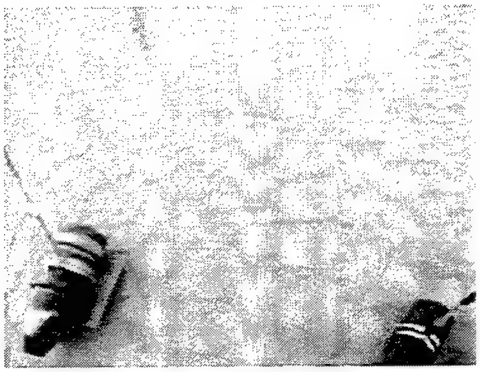


Site C41:SR (ROCK5)

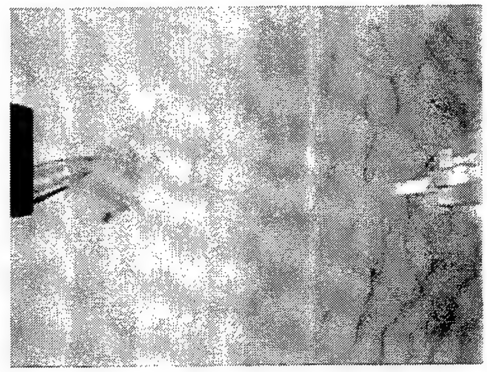


Site C42:SR (ROCK7)

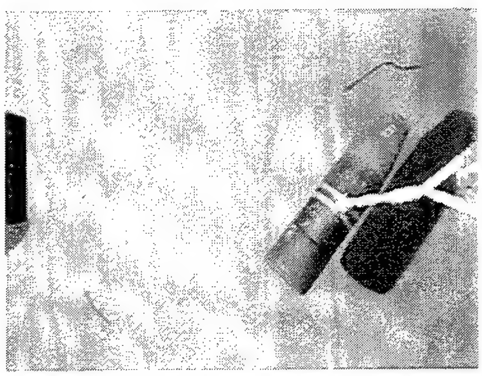
# Target Cells - Calibration Range



Site C43:SR (ROCK5)

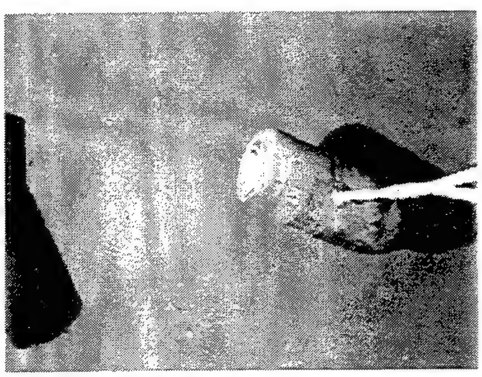


Site C44:SR (ROCK275)

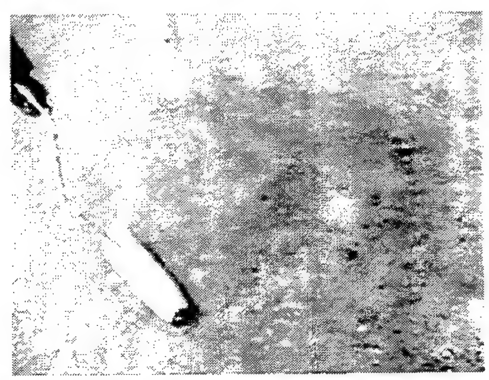


Site C45:SR (ROCK5)

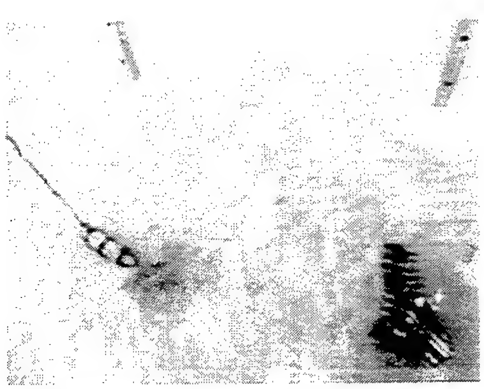
Site C46:SS (ROCK7)



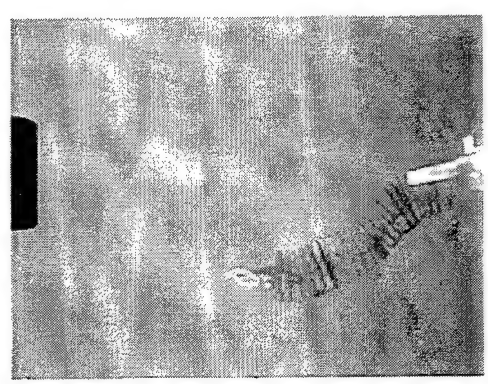
Site C47:SS (ROCK7)



Site C48:SS (ROCK5)

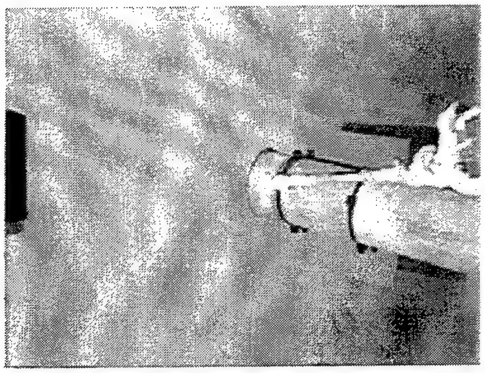


Site C49:SR (ROCK275)

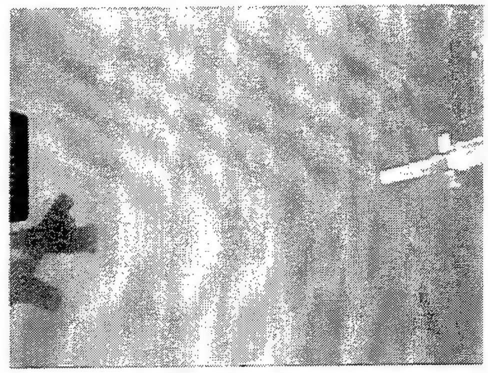


Site C50:SR (CART20M)

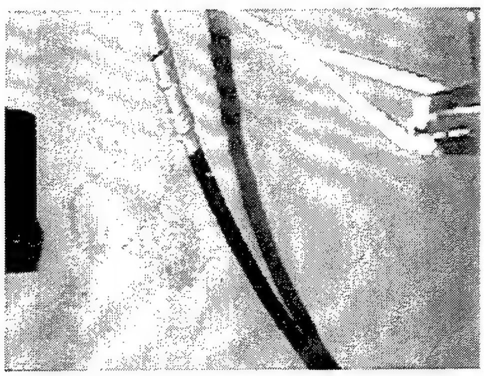
# Target Cells - Calibration Range



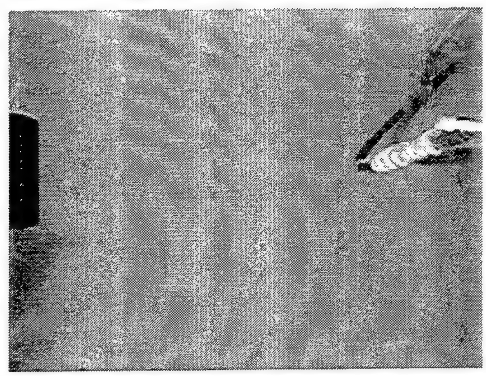
Site C51:SR (CART554)



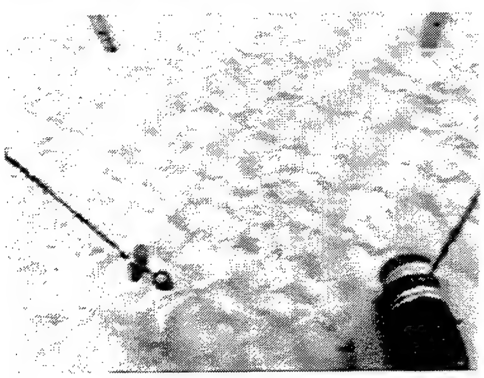
Site C52:SR (CASE40M)



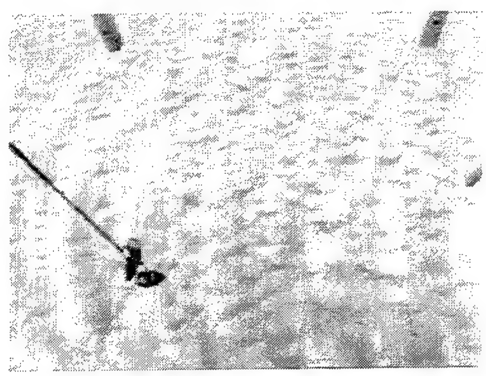
Site C53:SR (MK106)



Site C54:SS (CABLE)

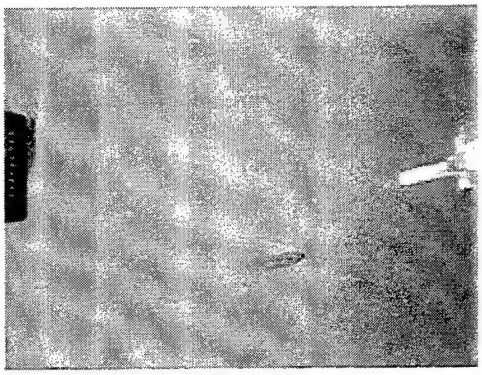


Site C55:SR (ROCK7)

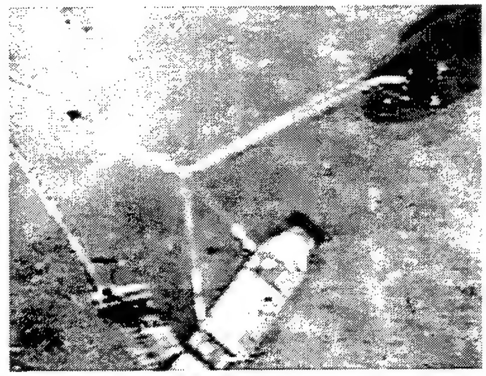


Site C56:SR (2ROCK275)

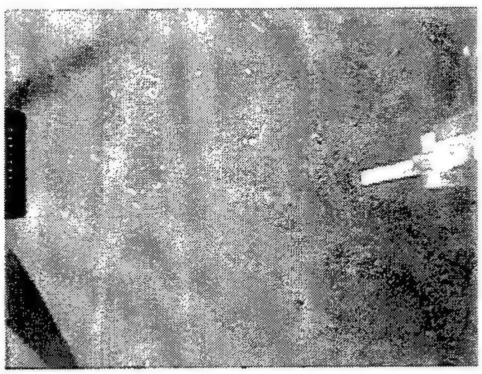
# Target Cells - Demonstration Range



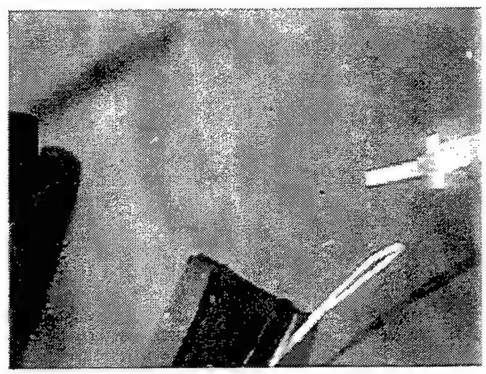
Site D1:SS (CART2OM)



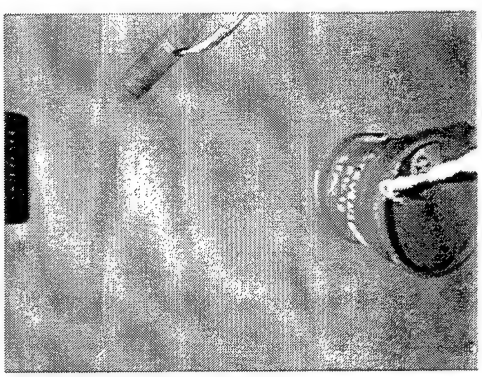
Site D2:RSA (FRAG)



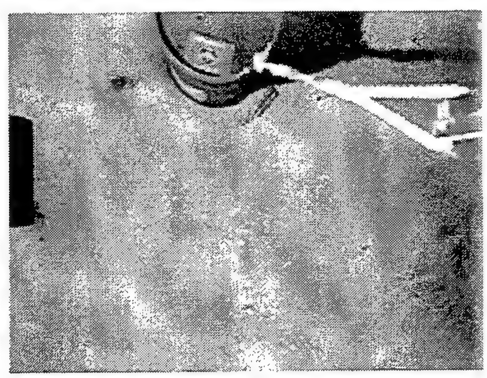
Site D3:RSA (PROJ554)



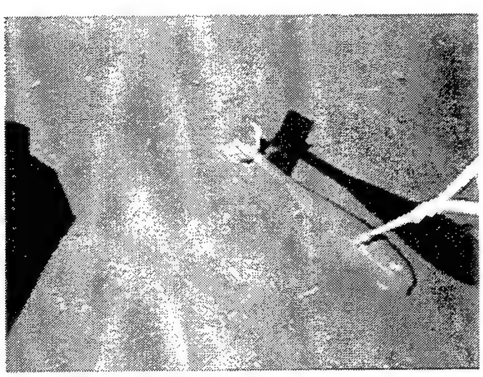
Site D4:SS (LDRUM)



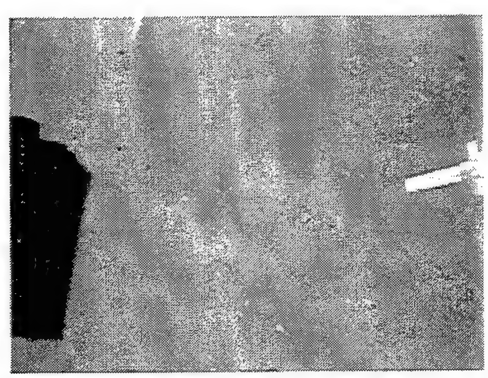
Site D5:SR (PROJ554)



Site D6:SS (MDRUM)

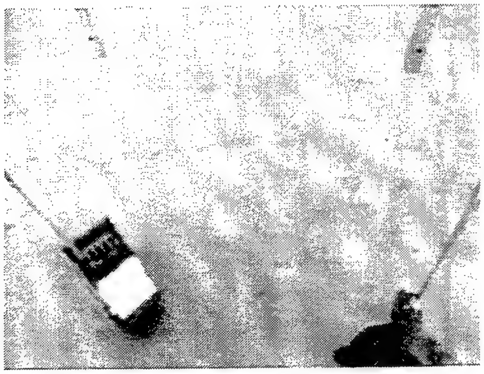


Site D7:SS (MK76)



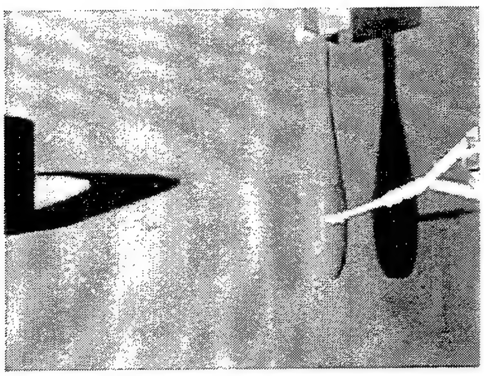
Site D8:SS (AMBOX)

# Target Cells - Demonstration Range

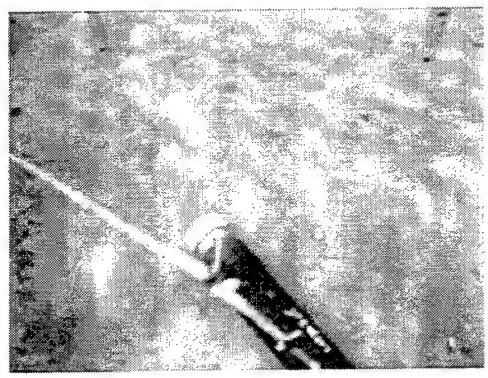


Site D9:SR (CHAIN)

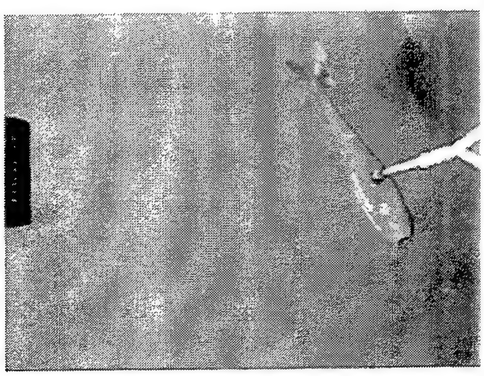
Site D10:SR (AMBOX)



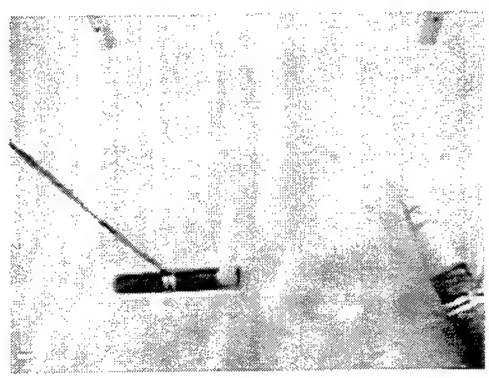
Site D11:SS (PROJ554)



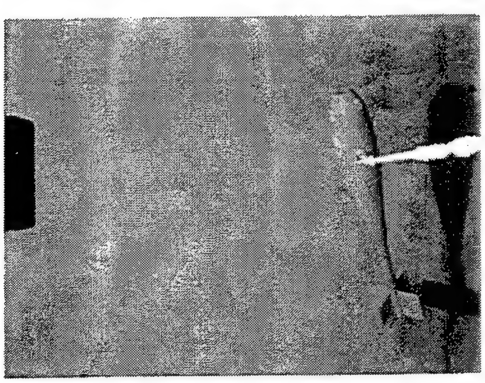
Site D12:SS (8SPIPE)



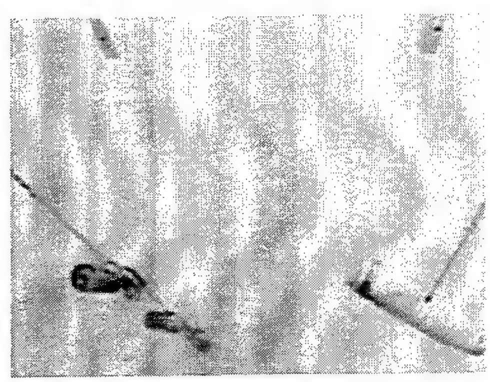
Site D13:SS (MK76)



Site D14:SW (PROJ554)

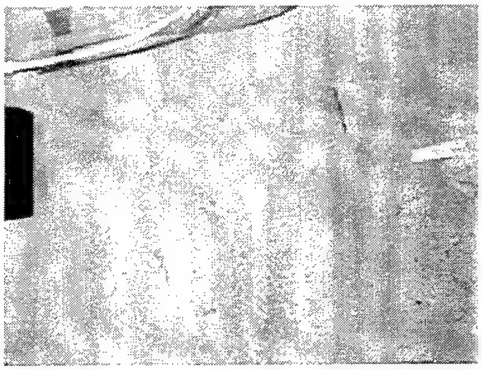


Site D15:SR (MK76)



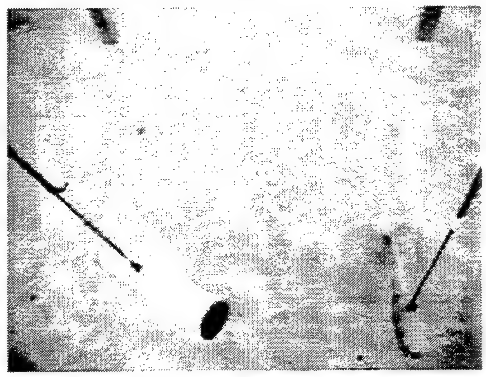
Site D16:SR (3MK106)

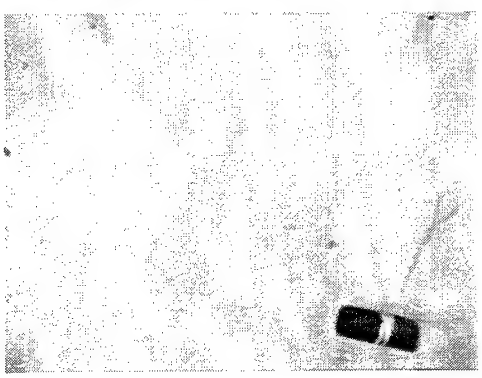
# Target Cells - Demonstration Range

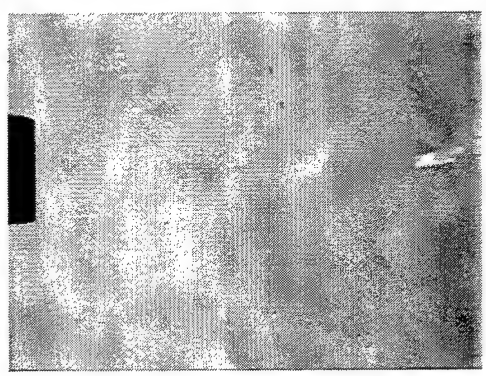

Site D17:SS (MK76)

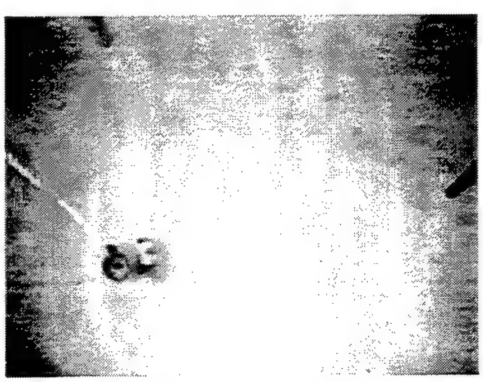

Site D18:SS (22LINK)

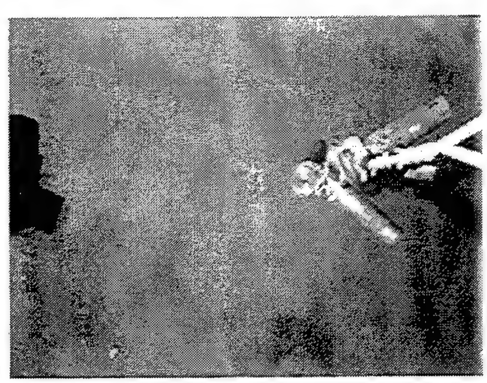

Site D19:SR (ROCK5)


Site D20:SR (5APIPE)

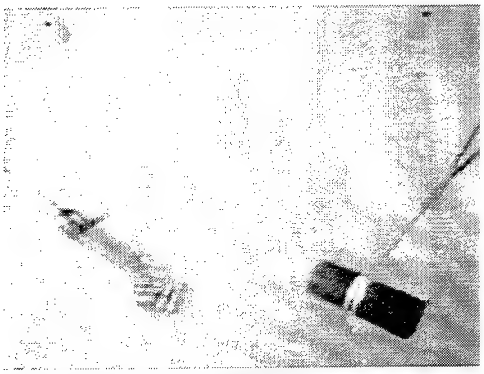

Site D21:SR (ROCK5)


Site D22:SR (3SPIPE))


Site D23:SR (MK106)

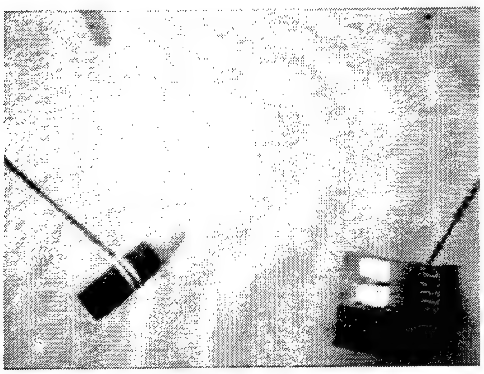

Site D24:SS (CASE40M)

# Target Cells - Demonstration Range

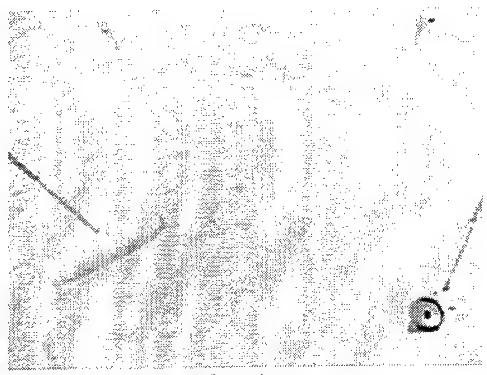


Site D25:SR (CART20M)

Site D26:SR (AMBOX)

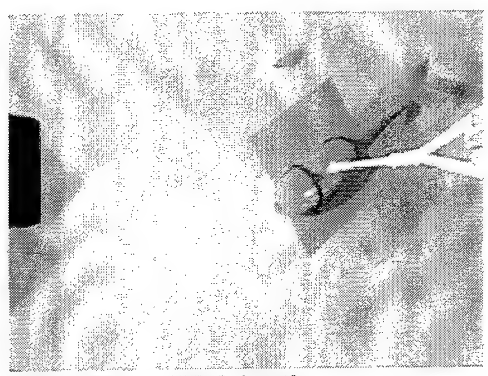


Site D27:SR (ROCK5)

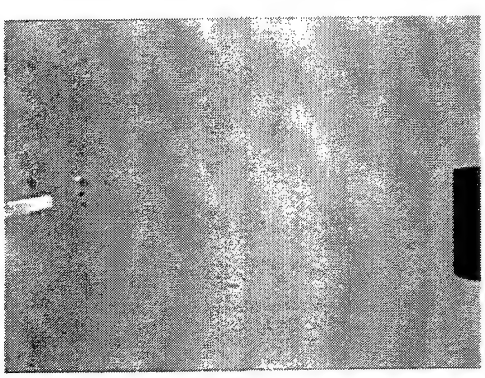


Site D28:SR (MK106)

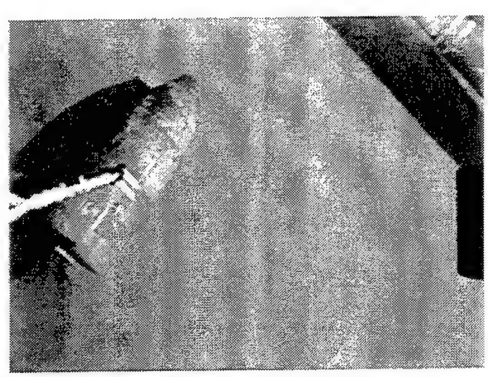
Site D29:SR (ROCK5)



Site D30:SR (PROJ538)

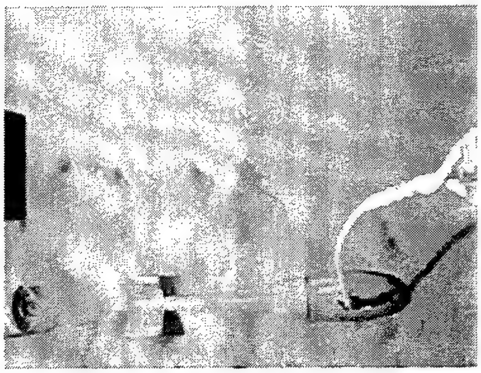


Site D31: SS(MK106)

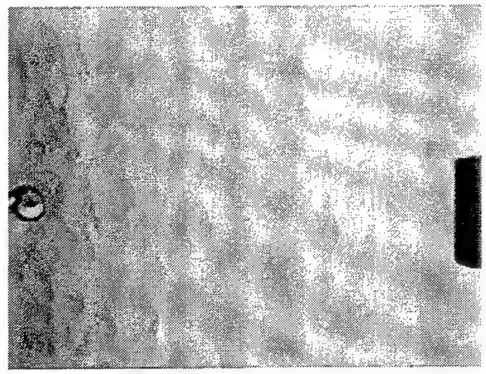


Site D32:SS (4SPIPEL)

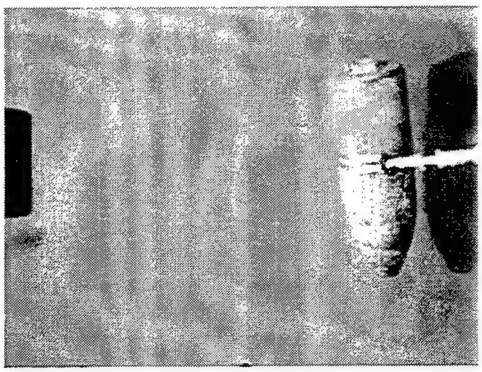
# Target Cells - Demonstration Range



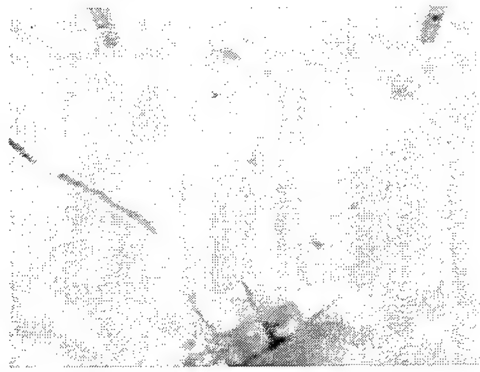
Site D33:SS (MK76)



Site D34:SR (ROCK275)

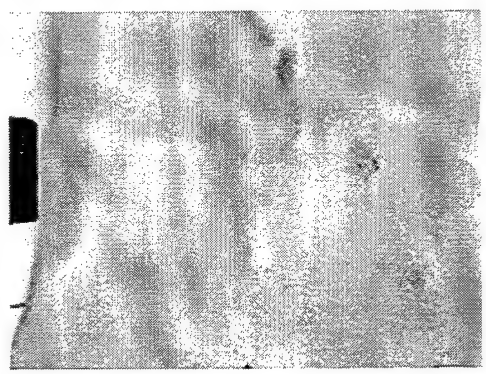


Site D35:SR (ROCK7)

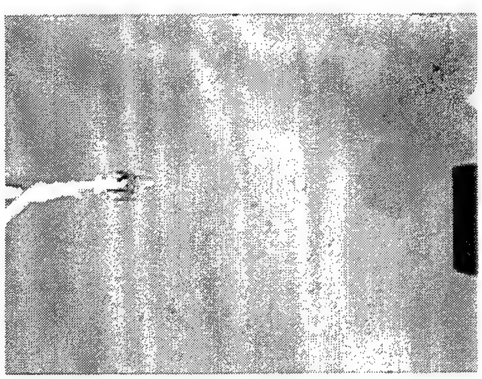


Site D36:SS (MK81)

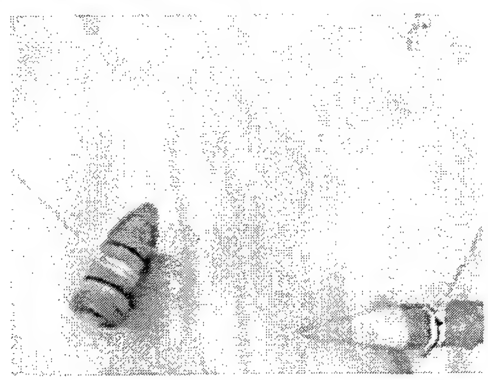
Site D37:SW (MK76)



Site D38:SS (MK82)

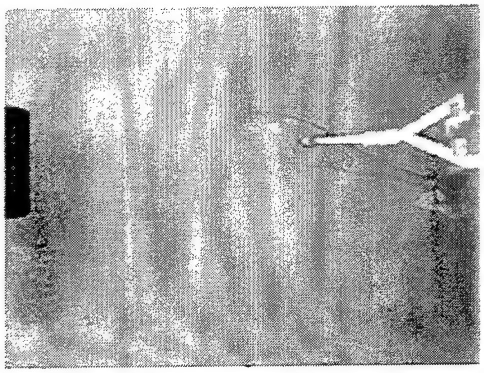


Site D39:SR (MK106)



Site D40:SR (PROJ554), D41 (TYP)

# Target Cells - Demonstration Range

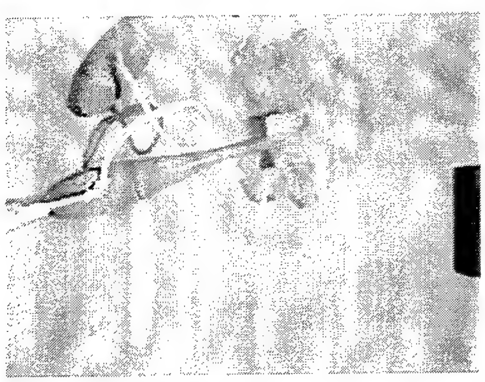


Site D42:SR (ROCK5)

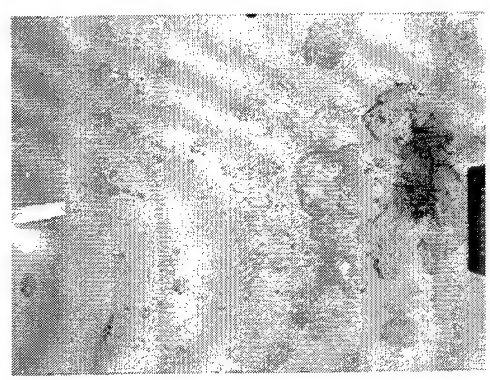
Site D43:R+S (CART554)

Site D44:SR (ROCK275)

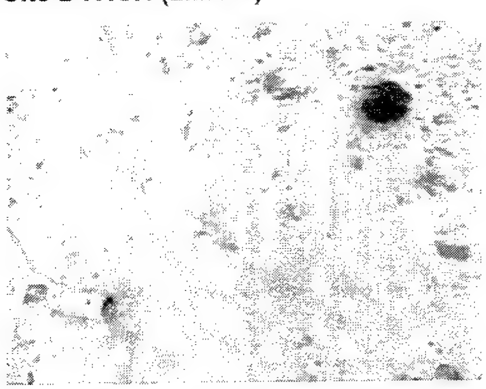
Site D45:R+S (ROCK7)



Site D46:SR (2MK76)



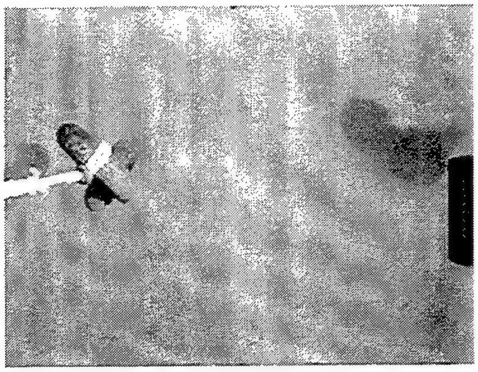
Site D47:R+S (2PROJ538)



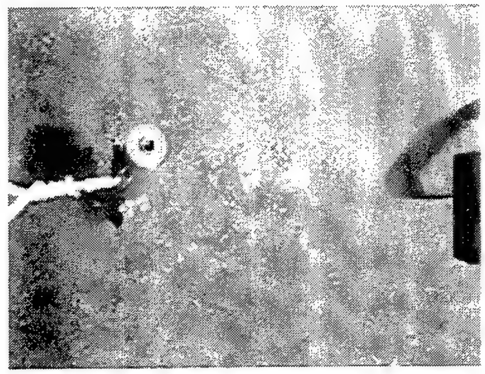
Site D48:R+S (MK106)

Site D50:SW (ROCK7)

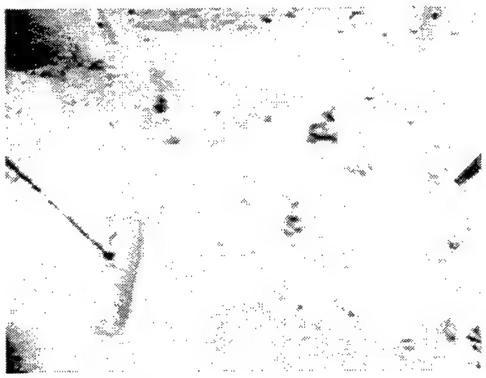
# Target Cells - Demonstration Range



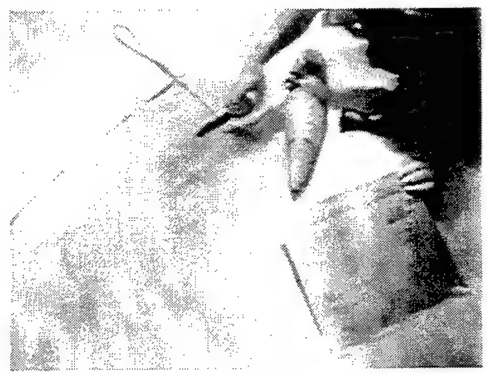
Site D51:SW (CLINK)



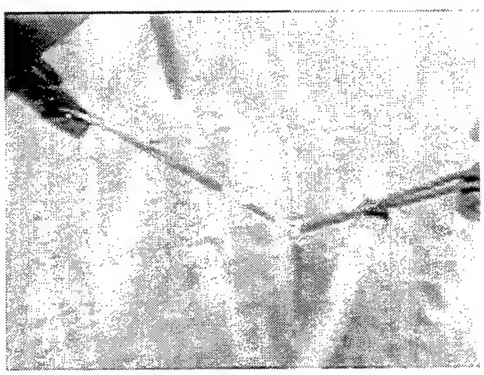
Site D52:RSA (MK106)



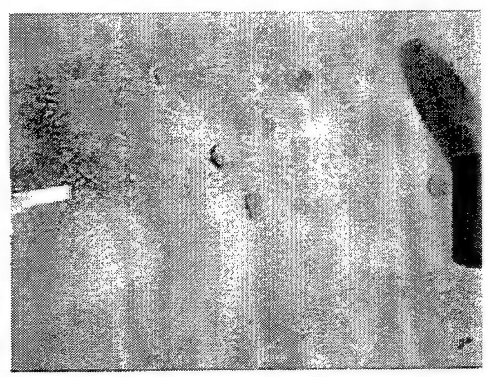
Site D54:R+S (2PROJ538)



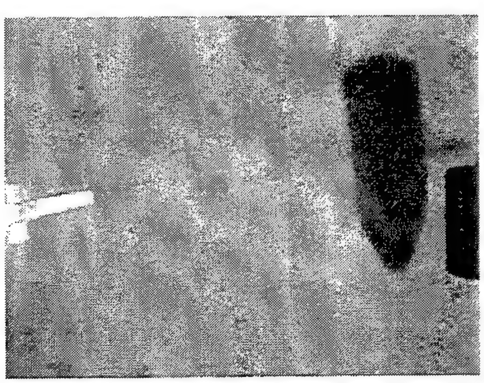
Site D55:SW (PROJ554), D49, D53, + D192 (TYP)



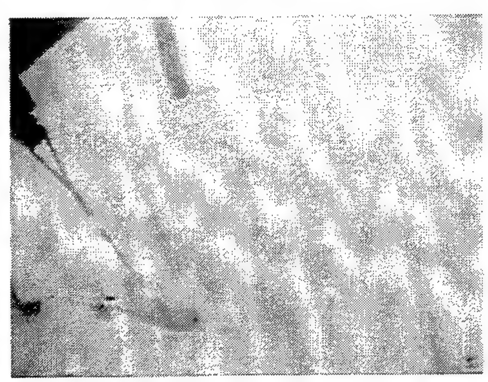
Site D56:SR (CART554)



Site D57:R+S (ROCK5)

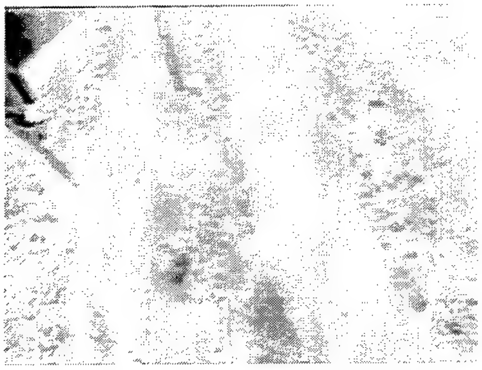


Site D58:R+S (ROCK7)

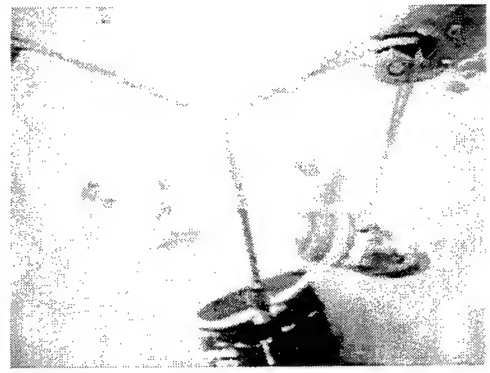


Site D59:SR (CART20M)

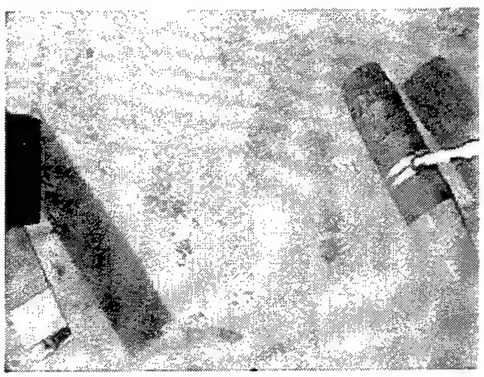
# Target Cells - Demonstration Range



Site D60:SW (MK76)

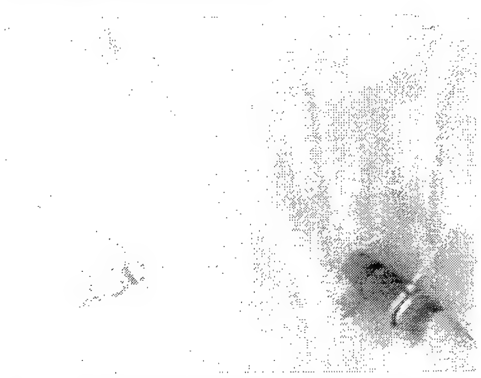


Site D61:R+S (LDRUM)



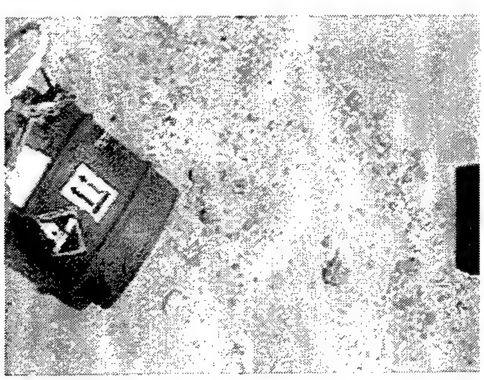
Site D62:R+S (IBEAM)

Site D63:SR (PROJ538), D64 (TYP)

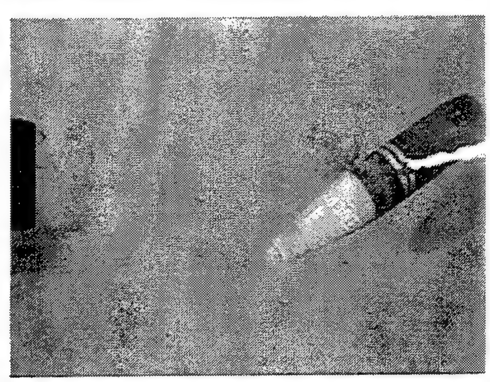


Site D65:SR (ROCK275)

Site D66:SR (PROJ554)

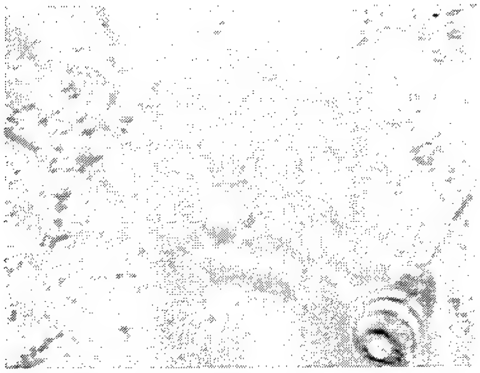


Site D67:R+S (MDRUM)

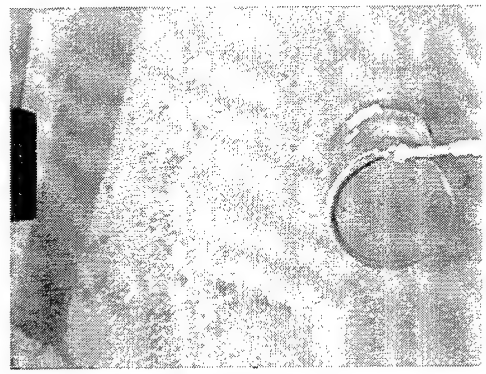


Site D68:R+S (PROJ554)

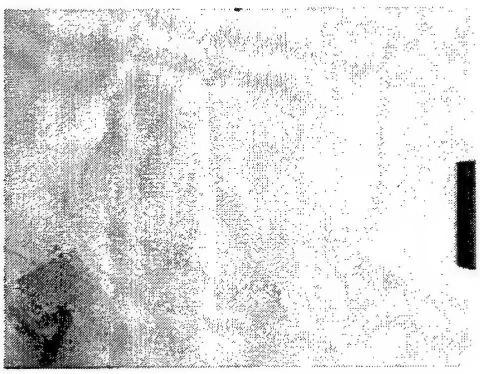
# Target Cells - Demonstration Range



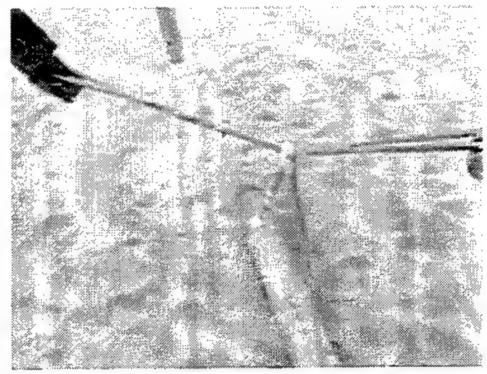
Site D69:R+S (ROCK7)



Site D71:R+S (MDRUM)



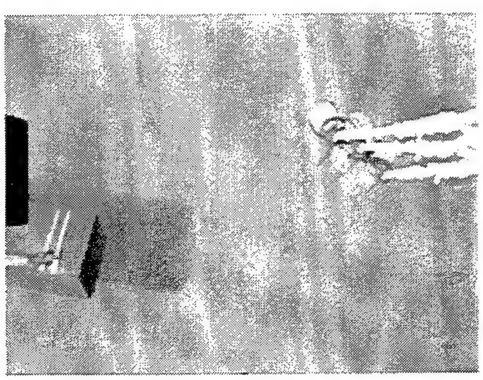
Site D72:SS (ROCK7), D70, D77,+ D78 (TYP)



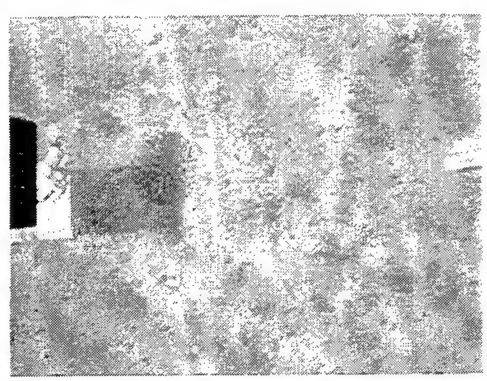
Site D73:SR (CART554)

Site D74:R+S (PROJ538)

Site D75:SR (CART20M)



Site D76:SS (BBEAM)



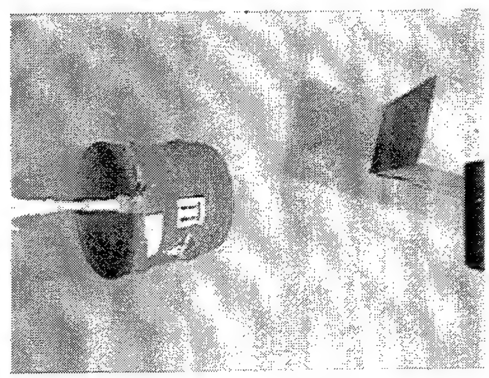
Site D79:R+S, C (CART554)

# Target Cells - Demonstration Range

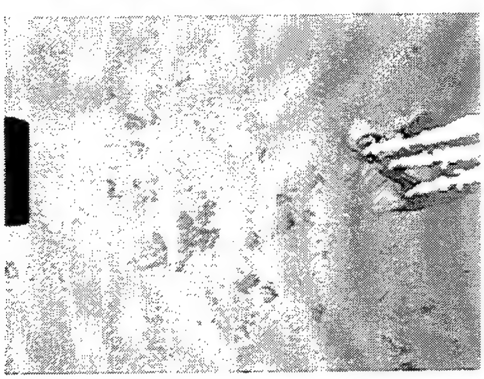
Site D80:SR (PROJ554)

Site D81:SW (ROCK5)

Site D82:SR (2PROJ538)

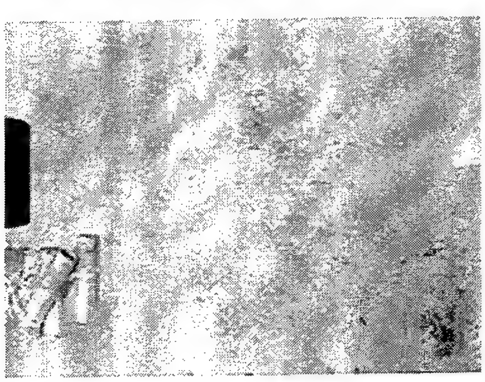


Site D83:SR (AMBOX)

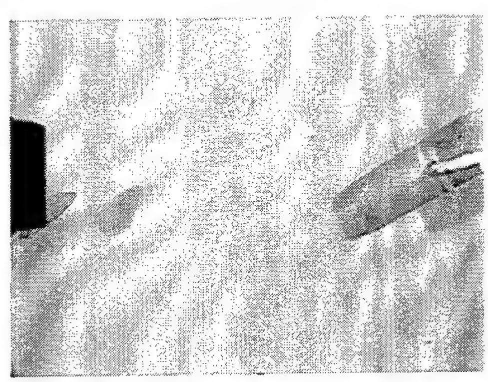


Site D84:R+S (3ROCK275)

Site D85:SR (ROCK7), D87 (TYP)

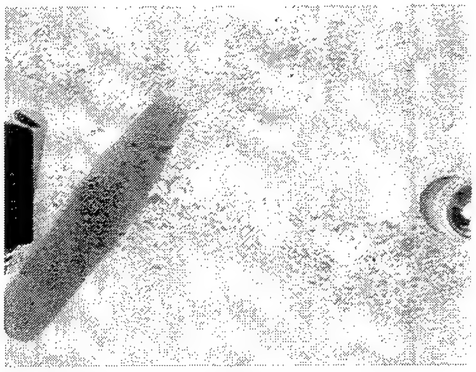


Site D86:SS (CASE40M)



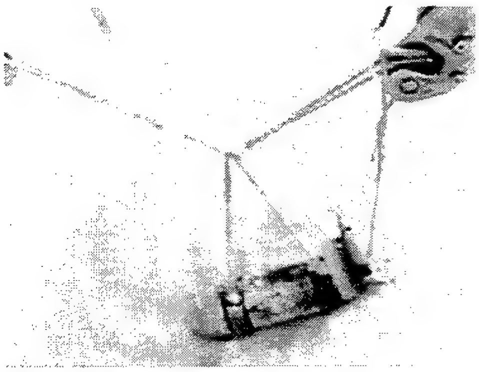
Site D88:SS (ROCK275)

# Target Cells - Demonstration Range

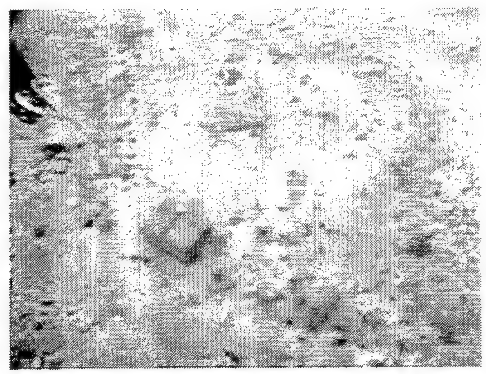


Site D89:R+S (PROJ554)

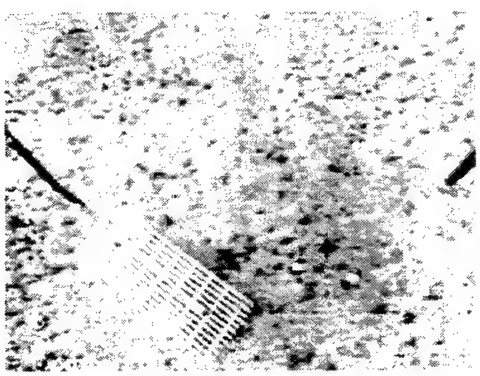
Site D90:RSA (FRAG)



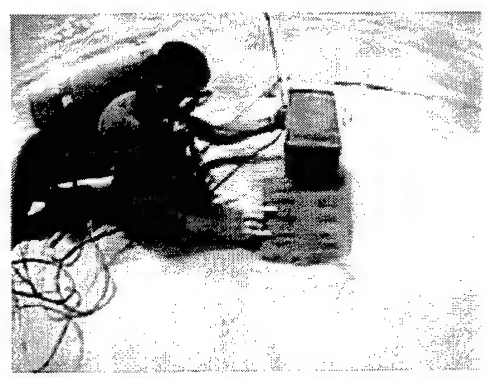
Site D91:SR (FRAG)



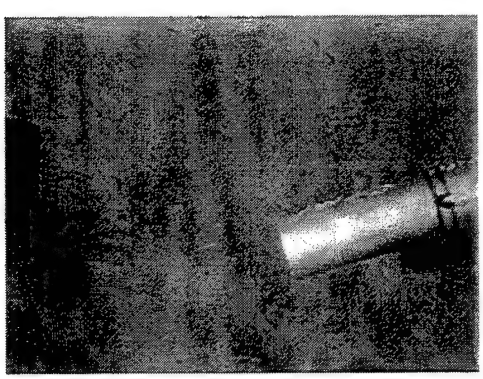
Site D92:R+S, (CART762)



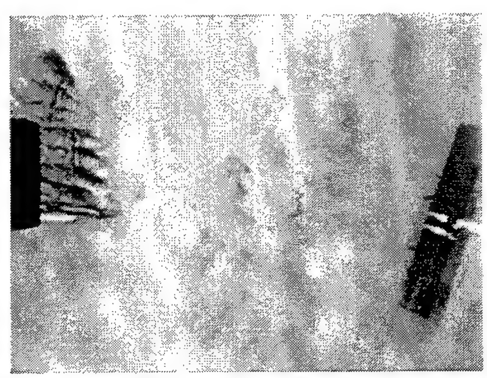
Site D93:RSA (GRATE)



Site D94:SS (AMBOX), D95+D99 (TYP)

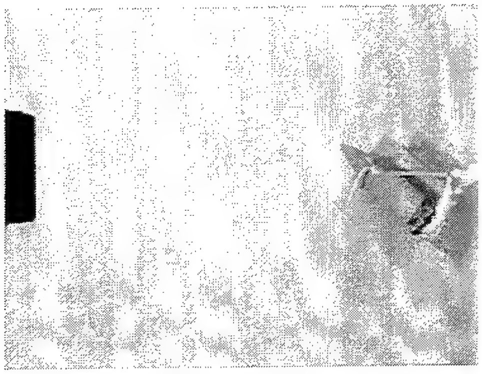


Site D96:SS (5APIPE)

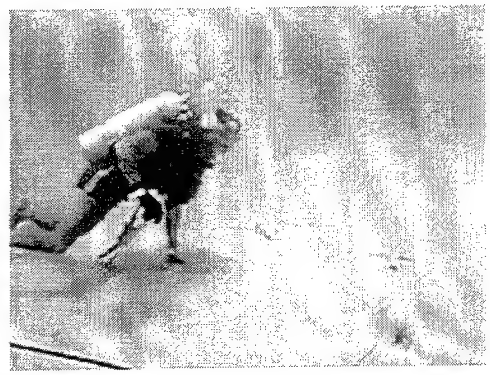


Site D97:SR (3SPIPE)

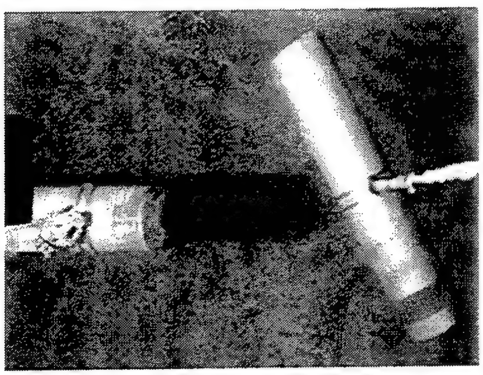
# Target Cells - Demonstration Range



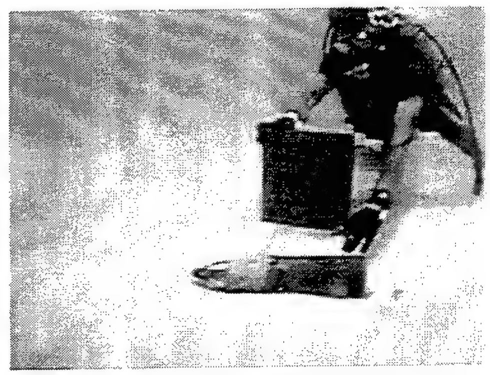
Site D98:SR (ROCK 275)



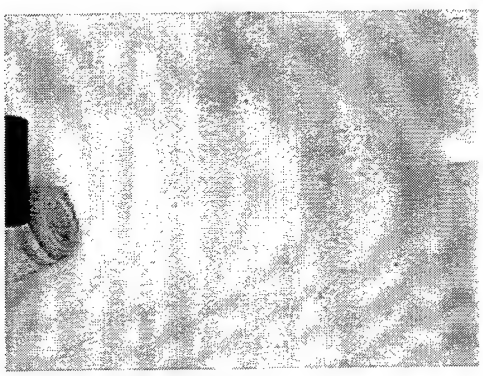
Site D100:SR (ROCK 275)



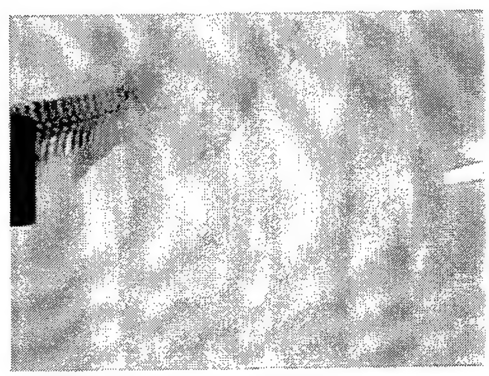
Site D101:R+S (CART554)



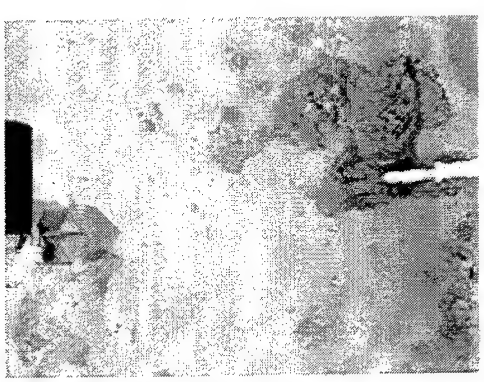
Site D102:SS (PROJ538), D193 (TYP)



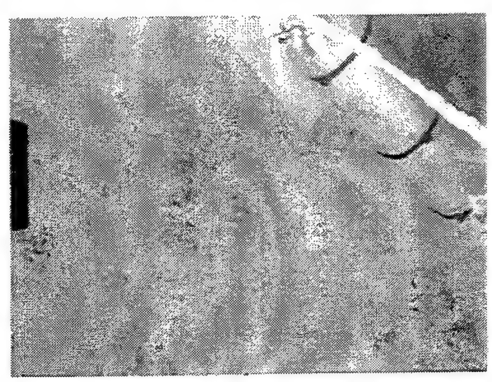
Site D103:SS (MK83)



Site D104:SR (CART20M)

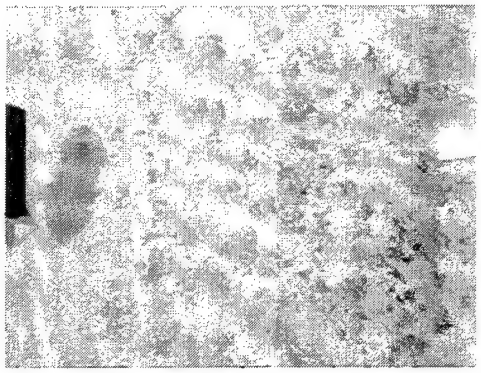


Site D105:R+S (LCHAIN)

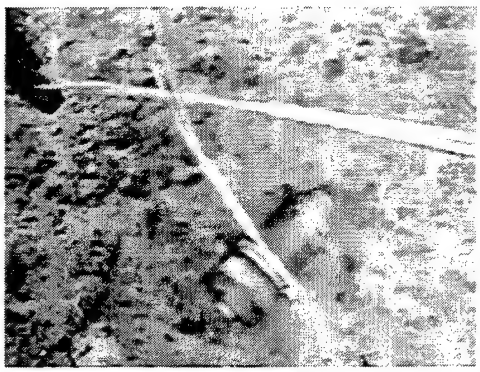


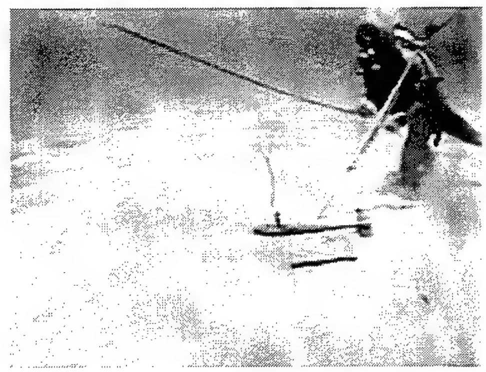
Site D106:R+S (CART554)

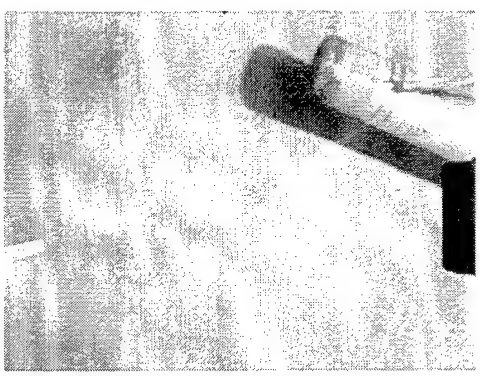
# Target Cells - Demonstration Range


Site D107:RSA (MK106)

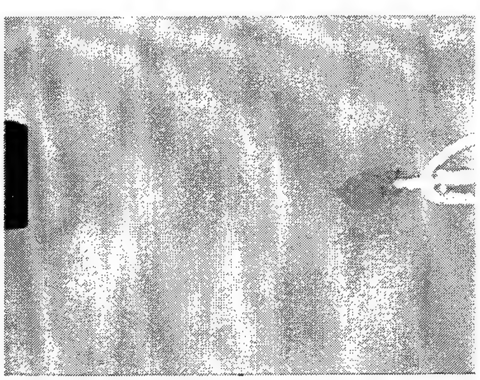

Site D108:R+S (12SPIPE)

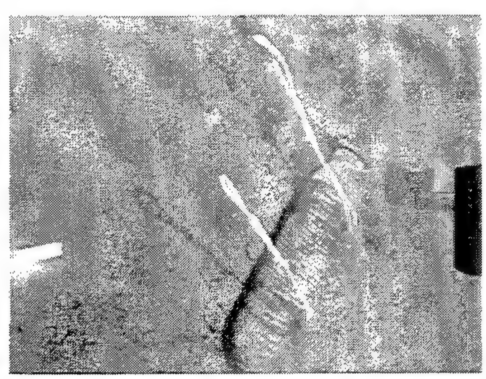

Site D109:R+S (ROCK7)


Site D110:SS (MK76), D161 (TYP)

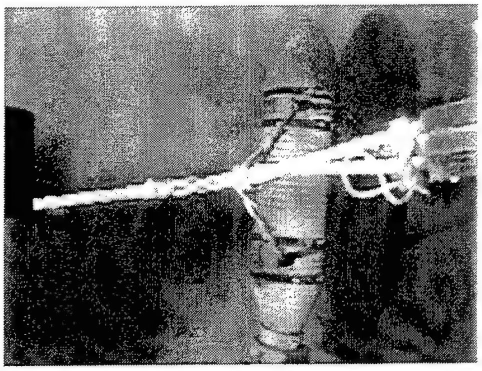

Site D111:SS (CART554)

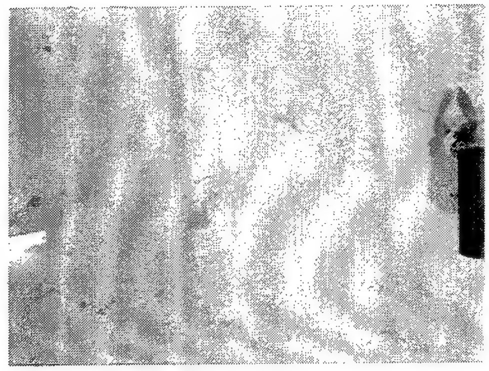

Site D112:SR (8SPIPE)

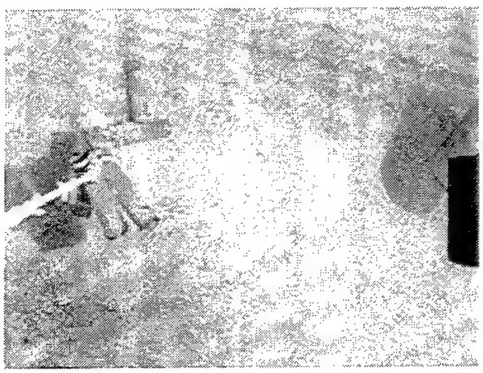

Site D113:SR (LCHAIN)

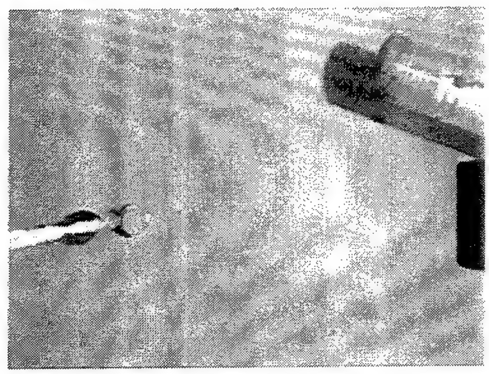

Site D114:R+S (FRAG)

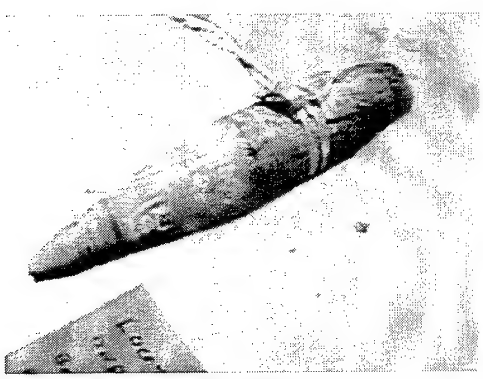
# Target Cells - Demonstration Range

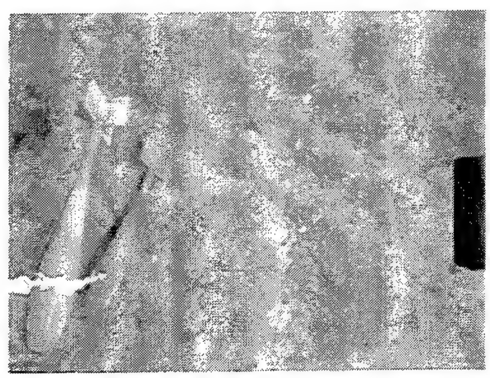

Site D115:SR (FRAG), D116+D120 (TYP)

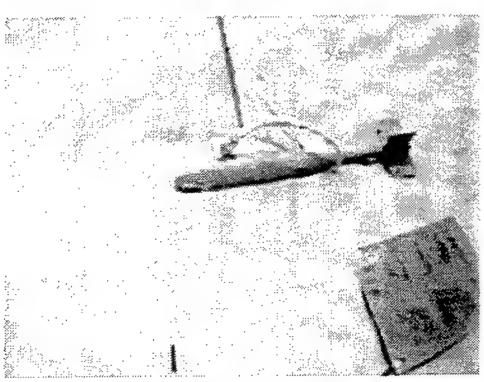

Site D117:SR (MK106)

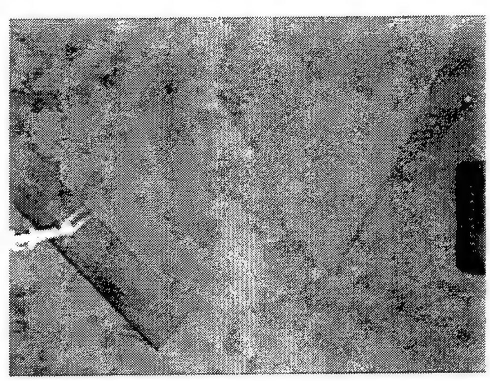

Site D118:SS (SDRUM)


Site D119:SS (ROCK275)

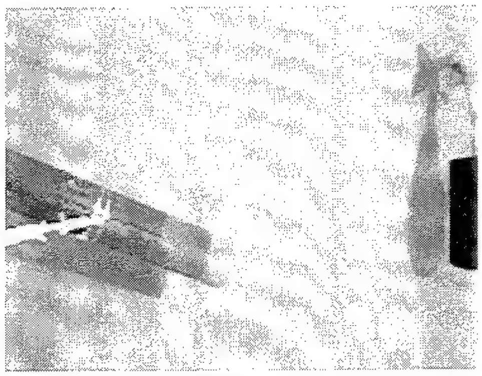

Site D121:SS (PROJ554)


Site D122:R+S (2MK76)

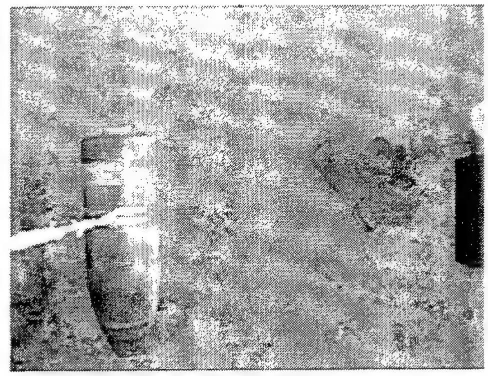

Site D124:SR (MK76), D123+D170 (TYP)


Site D125:ROF (4SPIPE)

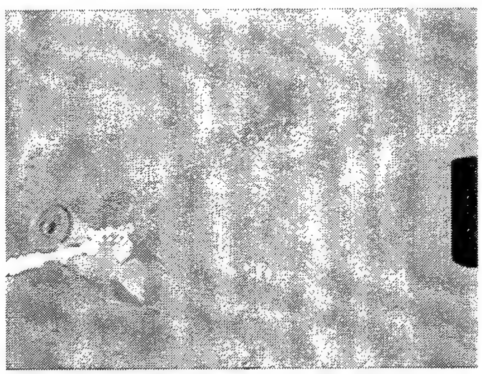
# Target Cells - Demonstration Range



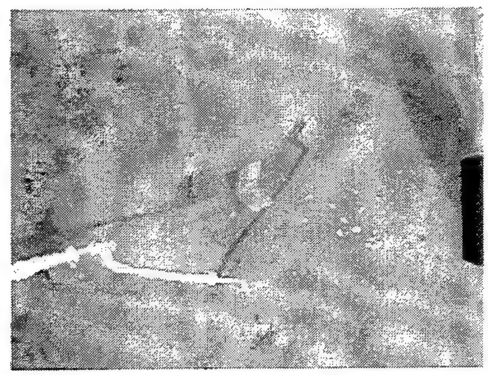
Site D126:SS (MK76)



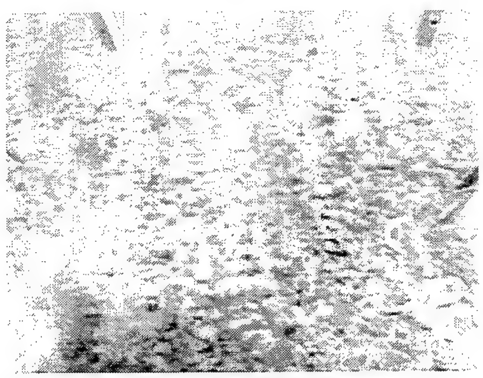
Site D127:R+S (3MK106)



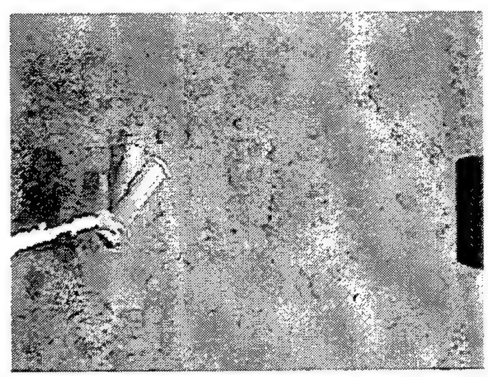
Site D128:R+S (3MK106)



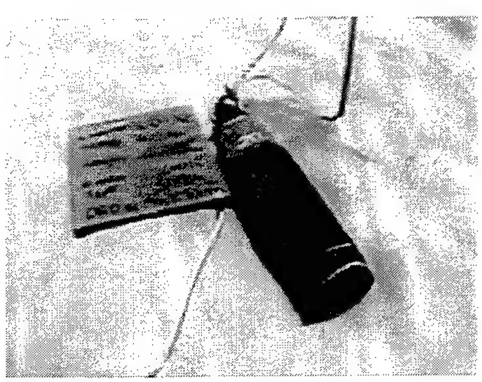
Site D129:R+S (PROJ554)



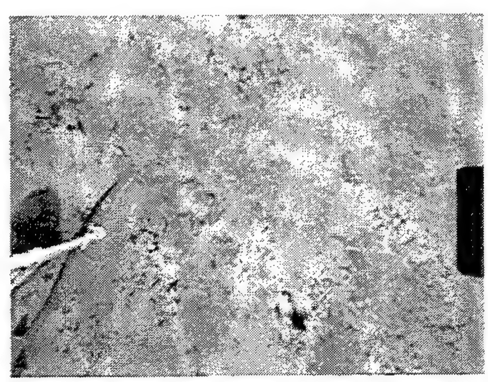
Site D130:RSA (CASE40M)



Site D131:R+S (CASE40M)

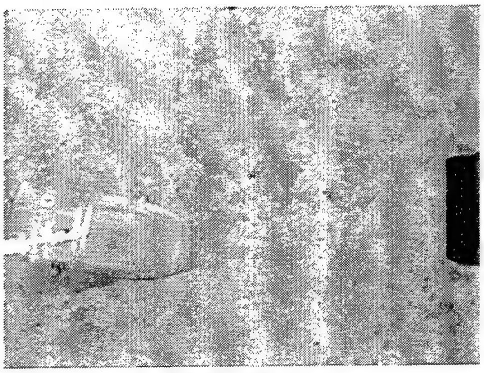


Site D132:SS (PROJ538), D136 (TYP)

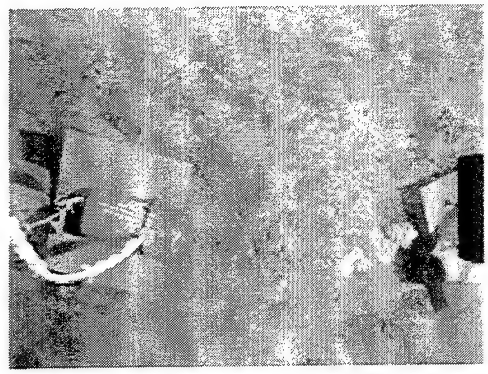


Site D133:RSA (2MK76)

# Target Cells - Demonstration Range

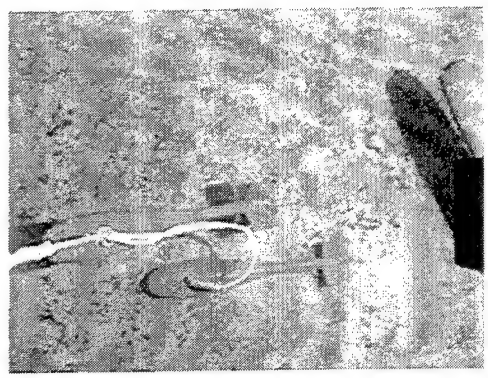


Site D134:R+S (ROCK7)

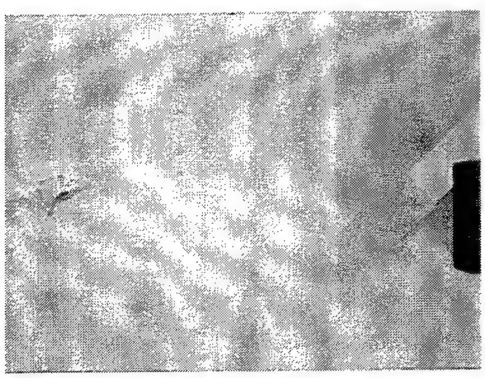


Site D135:RSA (MK106)

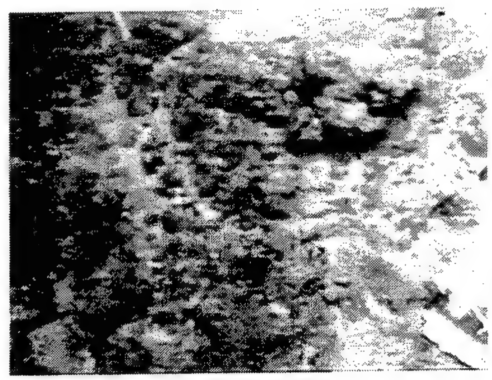
Site D137:CAVE (2ROCK5)



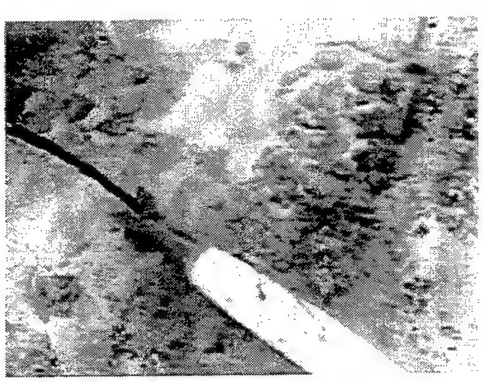
Site D138:RSA (ROCK5)



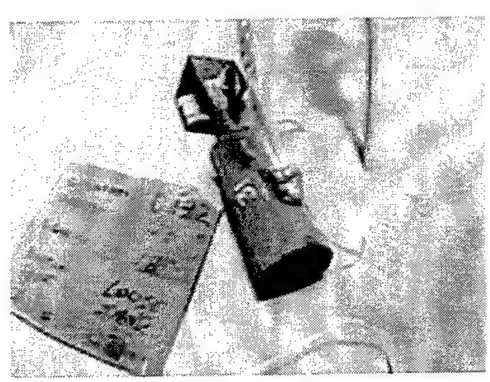
Site D139:SR (4SPIPE)



Site D140:ROS (PROJ538)

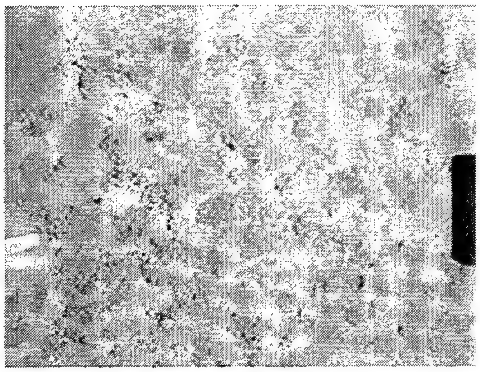


Site D141:ROF(MK82)

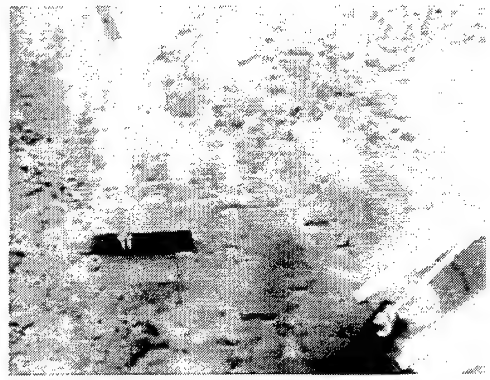


Site D142:SS (MK106)

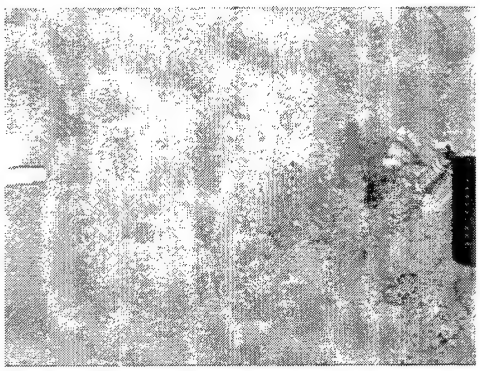
# Target Cells - Demonstration Range



Site D143:RSA (ROCK275)



Site D144:RSA (3SPIPE)



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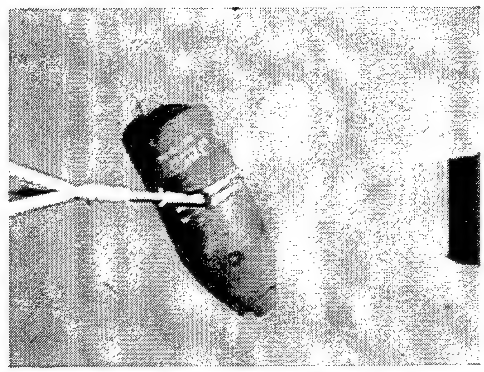
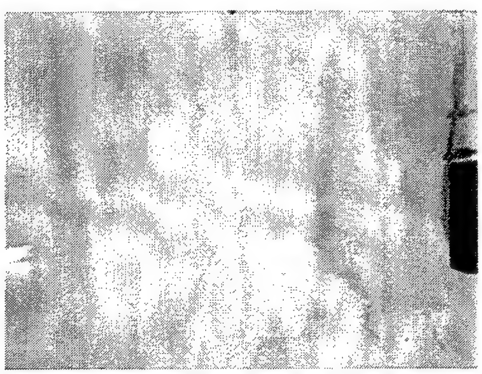
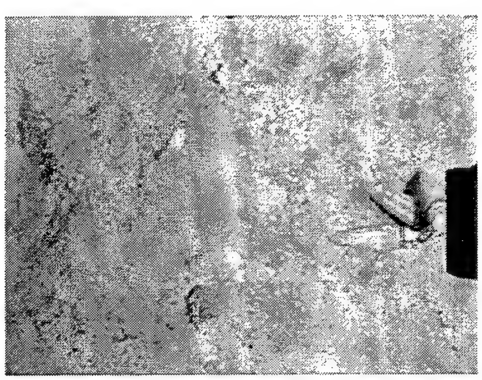


Site D146:SS (ROCK7)

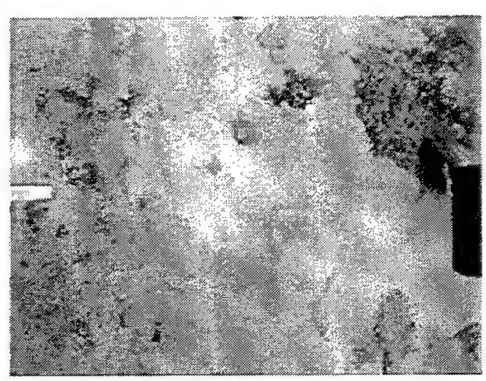


Site D147:SR (MK76), D151+D153 (TYP)

Site D148:ROS (ROCK7)

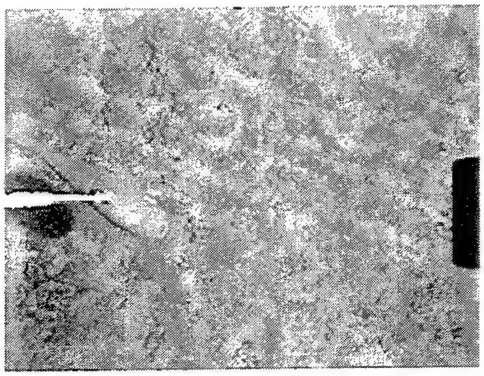


Site D149:R+S (3MK106)

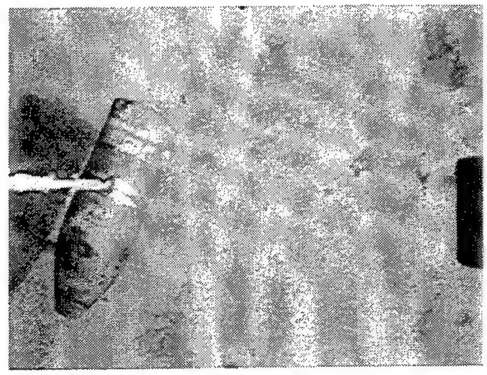


Site D150:RSA (3ROCK275)

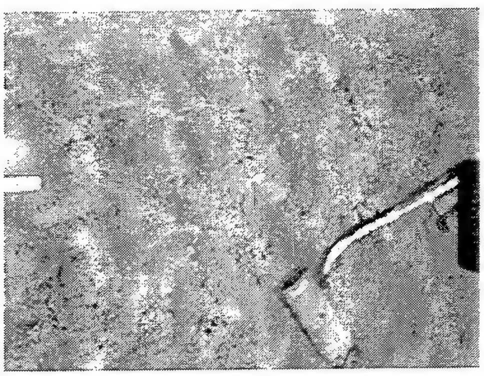
# Target Cells - Demonstration Range



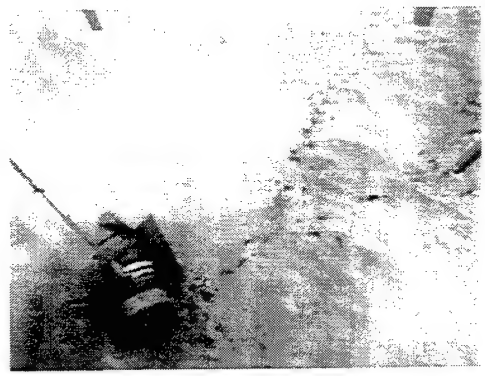
Site D152:RSA (MK76)



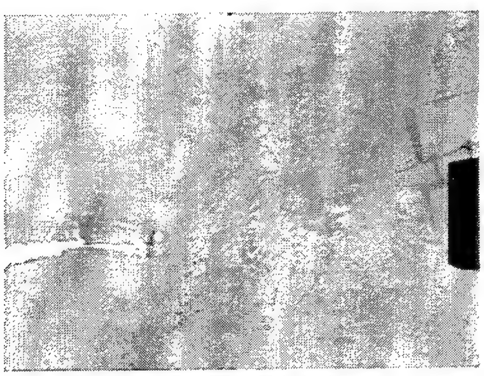
Site D154:R+S (ROCK7)



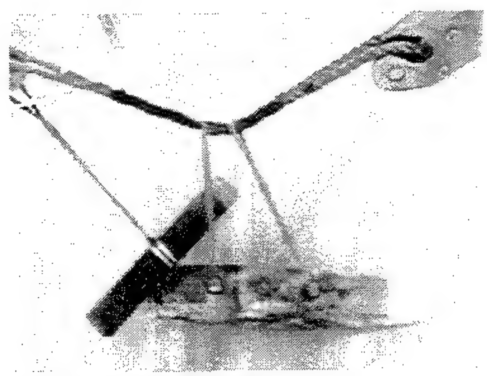
Site D155:RSA (MK106)



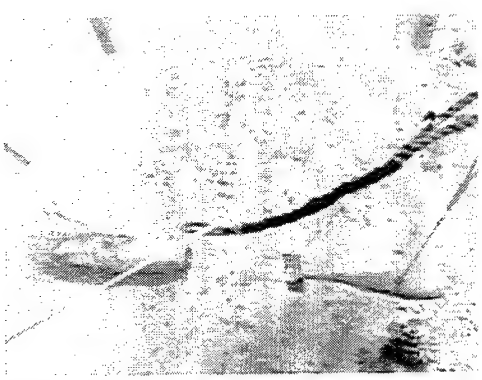
Site D156:SR (ROCK7)



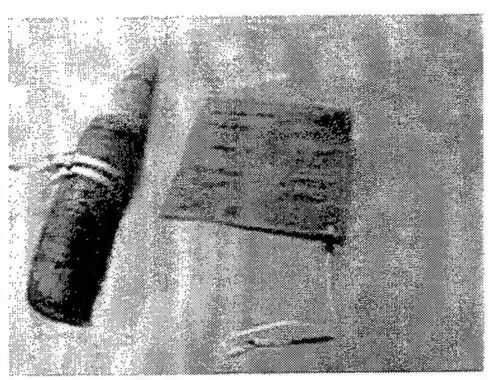
Site D157:ROS (ROCK275)



Site D158:SS (MK81)



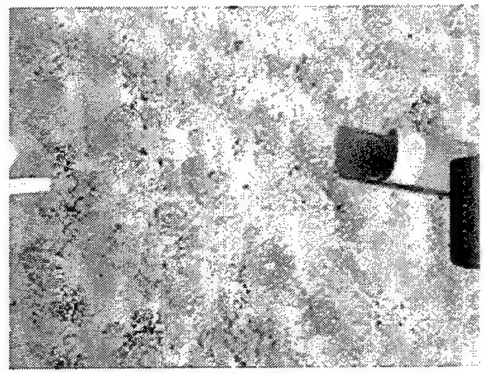
Site D160:SR (MK81)



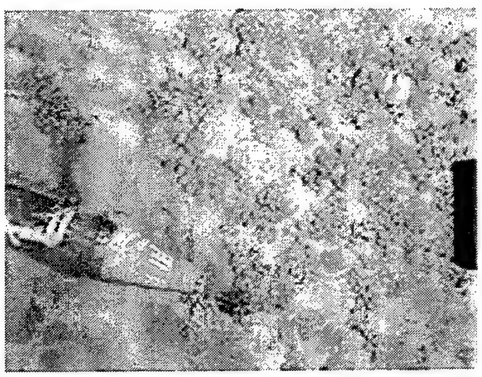
Site D162:SR (PROJ554), D159 (TYP)

# Target Cells - Demonstration Range

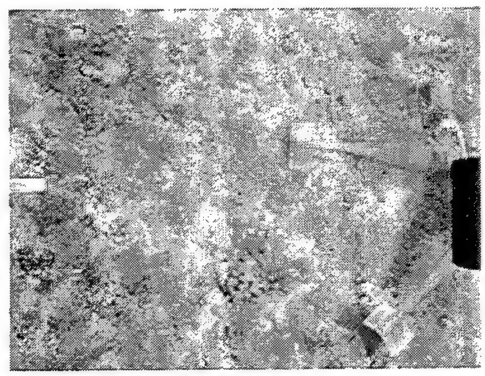
Site D163:RSA (MK76)



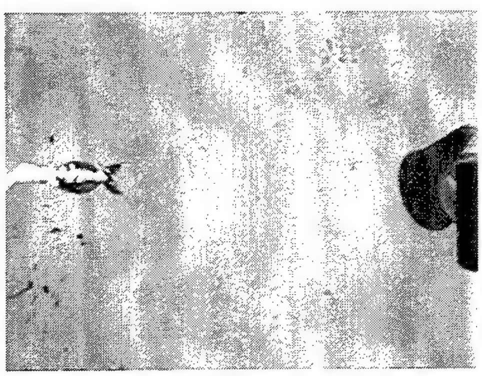
Site D164:RSA (4SPIPE)



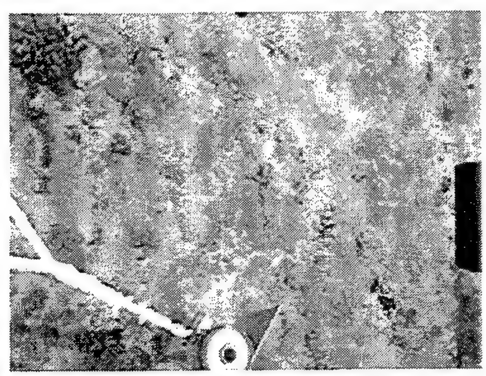
Site D165:RSA (PROJ554)



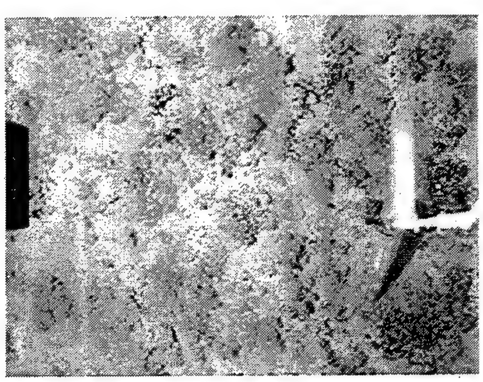
Site D166:RSA,C (2MK76)



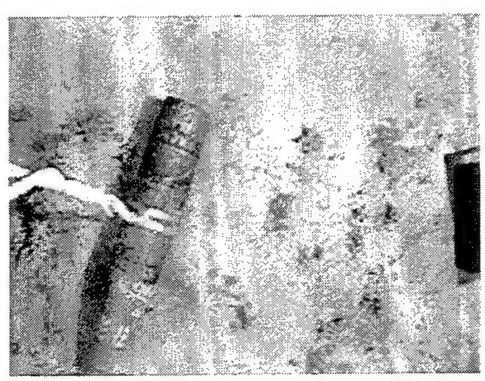
Site D167:SS (SDRUM)



Site D168:RSA,C (MK106)

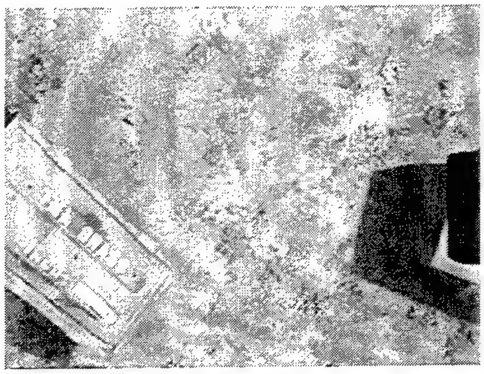


Site D169:RSA (ROCK275)

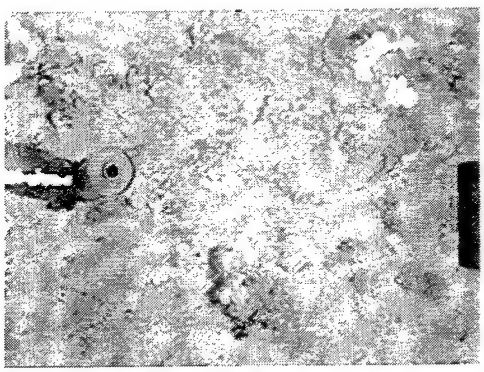


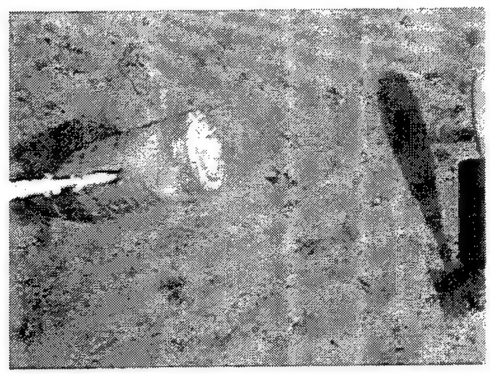
Site D171:R+S (ROCK275)

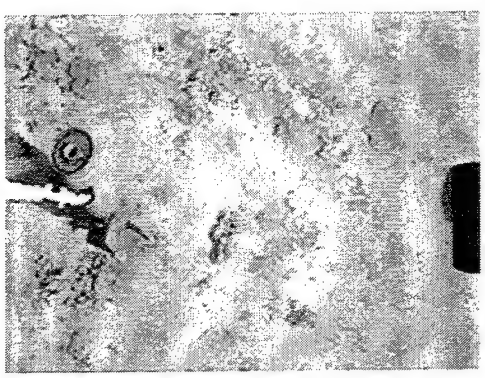
# Target Cells - Demonstration Range


Site D172:R+S (AMBOX)

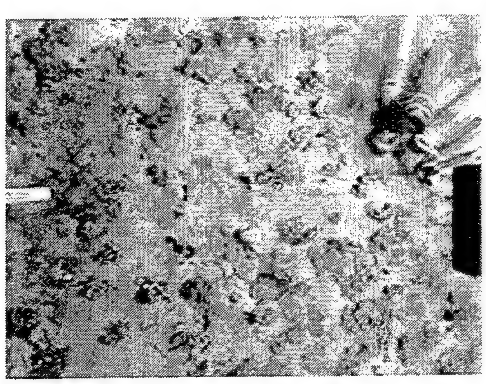

Site D173:R+S (ROCK7)

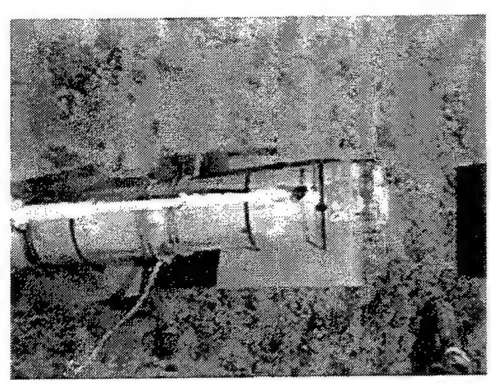

Site D174:RSA (MK106)


Site D175:R+S (MK76)

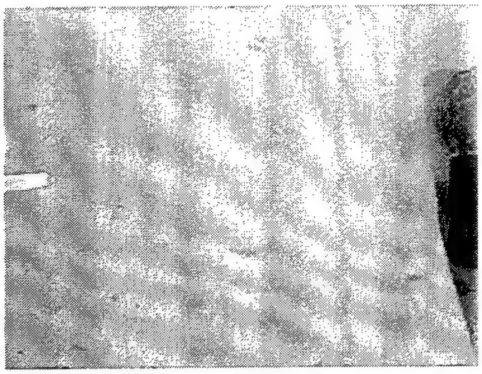

Site D176:R+S (ROCK275)


Site D177:SR (ROCK275)

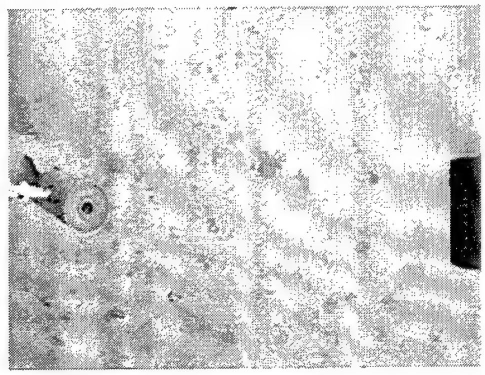

Site D178:RSA (CASE40M)


Site D179:RSA (CART554)

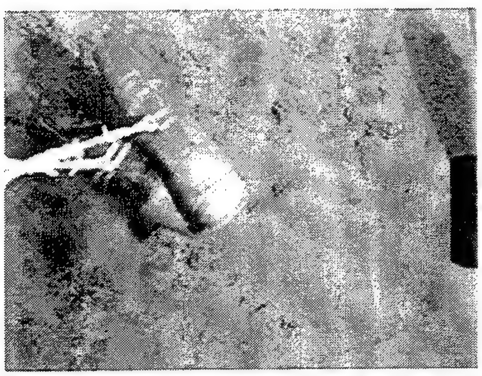
# Target Cells - Demonstration Range



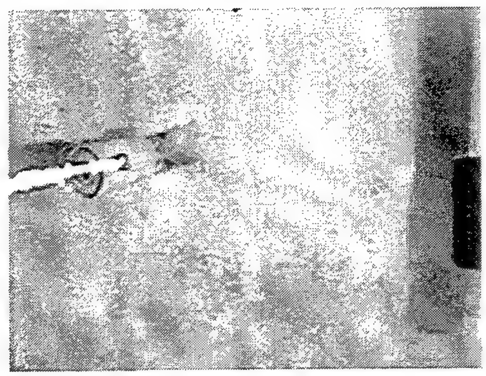
Site D180:SS (PROJ554)



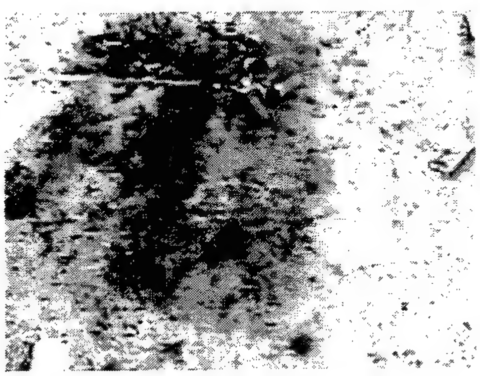
Site D181:R+S (MK106)



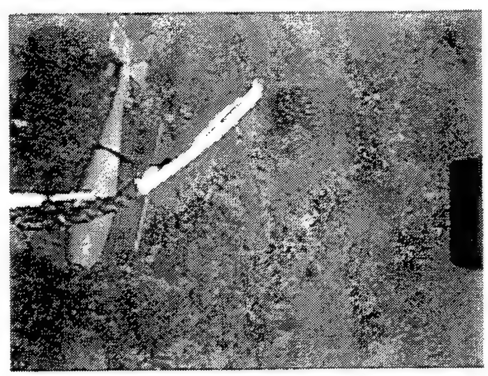
Site D182:RSA (2ROCK5)



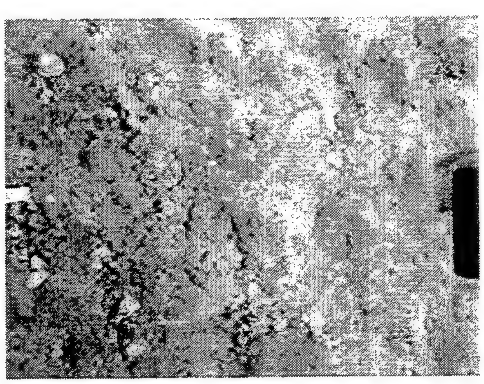
Site D183:R+S (5APIPE)



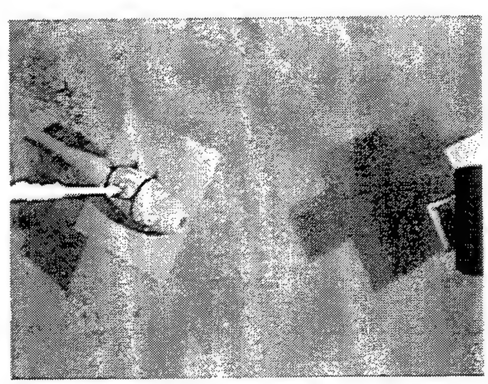
Site D184:RSA (FRAG)



Site D185:RSA (MK76)

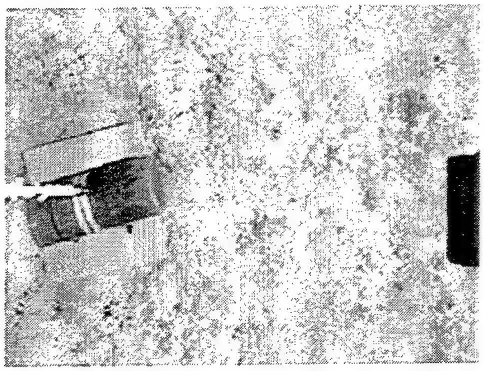


Site D186:RSA (MK106)

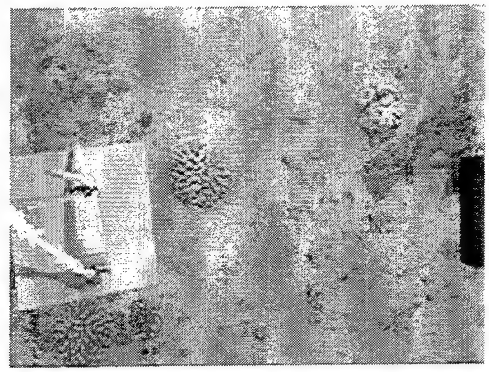


Site D187:R+S (MK76)

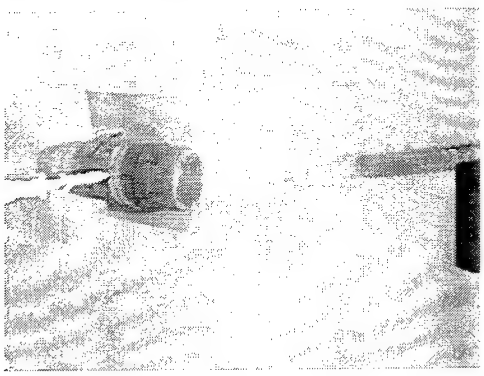
# Target Cells - Demonstration Range



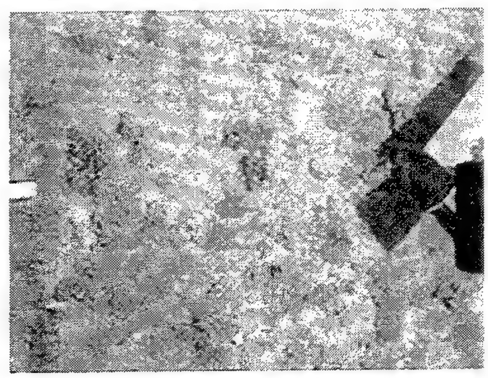
Site D188:RSA (ROCK5)



Site D189:R+S,C (ROCK275)



Site D190:SR (LCHAIN)



Site D191:RSA (MK106)

## APPENDIX C

## RANGE OPERATIONS

# C-1. General Discussion

The FY95 STMC range field operations procedures are divided into the following sections in this appendix: (1) range establishment, (2) unknown target remotely operated vehicle (ROV) survey/inspections, (3) range recovery, (4) schedule of events for each of the operations, (5) a description of the installation support craft and equipment, and (6) detailed procedures and schedules.

Table C-1 contains a summary schedule for the field work that was conducted in support of the project.

Table C-1. Range Summary Schedule

| DATES (1995) | LOCATION | RESP. ORG. | OPERATION | DAY COUNT |
|---|---|---|---|---|
| **RANGE ESTABLISHMENT** | | | | |
| 0'7/06 - 07/07 | Honolulu | NFESC | Mobilization | 2 |
| 07/08 | Transit | NFESC | Transit to Kauai | 1 |
| 07/09 - 07/25 | Port Allen/Range | NFESC | Establish Range | 17 |
| | | | Total Days = | 20 |
| **DEMONSTRATION** | | | | |
| 07/30 - 08/02 | Port Allen | MMTC | Setup/Move Eq. | 4 |
| 08/03 - 08/18 | Port Allen/Range | MMTC | Demonstration | 16 |
| | | | Total Days = | 20 |
| **RANGE RECOVERY OPERATIONS** | | | | |
| 08/19 | Port Allen | NFESC | Setup/Move Eq. | 1 |
| 08/20 - 09/09 | STMC Range | NFESC | Target Recoveries | 21 |
| 09/10 - 09/11 | Port Allen | NFESC | Prep. for Transit | 2 |
| 09/12 | Transit | NFESC | Transit to Oahu | 1 |
| 09/13 - 09/14 | Honolulu | NFESC | Demobilization | 2 |
| 09/15 | Honolulu | NFESC | Pack for Transp. | 1 |
| | | | Total Days = | 28 |
| | | | Grand Total Number of Days = | 68 |

Targets were installed in three distinctly different ocean environments in the STMC range. The differences in the environments that were of concern to the project (particularly for target installations) were with regard to water depth, water clarity, and wave and water current energies present. For simplicity, the three areas were designated as: (1) the wash zone (turbid water between breaking waves and the shore); (2) nearshore (approximately 3 to 10 meters water depth); and (3) offshore (10 meters to the outer boundary of the range). During a majority of the time that range operations were being performed, the nearshore environment was just seaward of breaking waves, and the seafloor in the offshore environment experienced very little wave energy.

Targets were marked differently in the wash zone than in the nearshore and offshore environments. The marking scheme for buried targets was, in general, the same as for targets laying on the seafloor.

The targets were marked four different ways, each serving a specific function:

a. Inert Ordnance - All inert ordnance objects were either blue in color (designating inert) or had a blue band painted around them. False targets, such as drums and I-beams, also had a blue band painted around them to indicate that these were project items.

b. Point of Contact - The exterior of each target was stamped or stenciled with a point of contact label (NFESC address, and duty officer phone number) in case of loss.

c. Relocation/Recovery Line - A short length of floating line was attached to each of the targets. A soft eye was made in the floating end (toward ocean surface) of the lines. For buried targets (inadvertently buried by wave/water current action or buried intentionally by project personnel), the end of the line floated above the seafloor to indicate where the target was located. For both buried and seafloor resting targets, the eye in the line also served as an attachment point for recovery.

d. Surface Marking (wash zone targets only) - The only targets that had surface markings were the ones installed in the wash zone. A small diameter wire rope was attached from each of the wash zone target anchors to an anchor on the beach. The wire rope was buried using shovels from the beach anchor point to the low tide watermark. Wave action buried the wire rope from the low tide watermark to the target location. The anchor point on the beach for the wash zone targets was hidden in beach perimeter brush (to hide from the airborne optical sensor).

## C-2. Range Establishment

Establishment of the STMC range was supervised and performed by NFESC and consisted of vessel mobilization, DGPS shore station setup at PMRF, and the precise installation of targets

within the range boundaries. Table C-2 is the summary schedule of events for establishment of the range.

Table C-2. Range Establishment Schedule Summary

| DATES (1995) | LOCATION | RESP. ORG. | OPERATION | DAY COUNT |
|---|---|---|---|---|
| **STMC RANGE ESTABLISHMENT** | | | | |
| 0'7/06 - 07/07 | Honolulu | NFESC | Mobilization | 2 |
| 07/08 | Transit/PMRF | NFESC | Vessel Transit to Kauai/ Shore Station Setup | 1 |
| 07/09 - 07/25 | Port Allen/Range | NFESC | Establish Range | 17 |
| | | | Total Days = | 20 |

### C-2.1 Vessel Mobilization

Mobilization of the M/V American Islander was performed in Honolulu, Hawaii, at the home pier space of the M/V American Islander. American Workboats provided mobilization personnel and equipment support.

### C-2.2 DGPS Shore Station Setup

On the day following mobilization, the vessel transited to Port Allen, Kauai. Approximately 12 hours were required for the transit. NFESC project personnel traveled to Kauai early on that same day. Upon arriving on Kauai, the NFESC project team set up the DGPS shore station at the Bore Sight Tower on PMRF.

### C-2.3 Target Installations

The M/V American Islander was used to perform target installations in the offshore environment only (10 meters and deeper water depth). The NFESC dive locker personnel performed installations in water depths ranging from approximately 3 meters to 10 meters. The NFESC dive locker personnel also installed all targets in the wash zone. The wash zone targets were relatively small in size and weight, and were capable of being hand carried out to the wash zone installation positions from shore.

Fifteen targets were buried in both the nearshore and offshore environments. Target burials were performed by divers using small inflatable boats as surface support platforms. The targets that were assigned to be buried in the offshore environment were installed from the M/V American Islander. Divers relocated these targets for burial using target position information obtained on the M/V American Islander during their installations. Burial of these targets took place within a few hours after the targets had been installed.

The M/V American Islander tied-up at the Port Allen pier each night. Project personnel met on the M/V American Islander at the start of each target installation day. A discussion regarding the events that were planned for that particular day was given by the Test Director as the M/V

American Islander transited to the STMC range. This transit took approximately 1 hour. Safety concerns for the operations that were conducted that day were also covered at the meeting. Gear preparation was conducted following the meeting, while the vessel was still in transit. Installations began immediately after arriving on the range.

**C-2.3.1 Offshore Target Installations (M/V American Islander).** Figure C-1 is a concept drawing for the installation of targets in the offshore environment (10 meters water depth to the outer boundary of the STMC range). A specially designed deployment package was used off the M/V American Islander to install targets. The deployment package consisted of a steel frame that housed and protected an assortment of instruments used to observe and document the installations as they were taking place. The installation process was designed to maintain maximum control of the targets until release. Each target was lowered to the seafloor as the vessel held station. The altimeter on the deployment package was used to "see" the seafloor approach before a visual image of the seafloor was obtained with the deployment package video camera. Targets were not released until the Test Director verified that the vessel was within the drop area for that particular target, and the condition of the seafloor was observed with the deployment package video camera. The pre-release visual observation of the surrounding seafloor area was needed to reduce the possibility of environmental damage caused by inadvertently placing a target on delicate marine life, and to ensure that a target was not placed on a man-made object not known to be in the area. Two targets at a time were attached to the deployment package. Once satisfied with the drop location, one of two mechanical release mechanisms at the deployment package was triggered to release the target. A position fix was immediately taken on the target with the integrated navigation system, and the water depth, target heading, and release time were automatically logged. The responder on the deployment package provided sub-surface position data, and the DGPS provided surface position data to the integrated navigation system. The target deployment package compass and depth gage were interfaced with the integrated navigation system. Offsets for each system or system component were entered into the integrated navigation system prior to the start of operations.

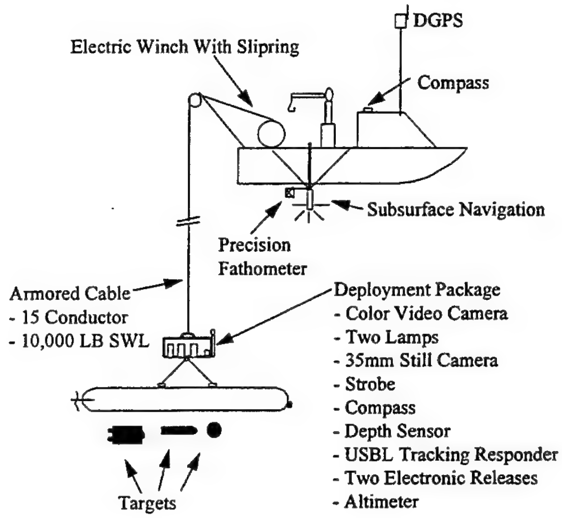


Figure C-1. M/V American Islander Target Installation Components

As the deployment package was being recovered, 35-mm photographs were also taken. These photographs, along with the video recording, documented the condition of the target and surrounding seafloor at, during, and immediately following the time of release. With the second target still attached, the vessel maneuvered to the next installation location.

All of the instruments on the package were already owned by NFESC. Therefore, this approach provided a relatively low cost way to ensure positive control of the targets during installation, and good documentation of results.

Section 6.0 gives a step-by-step list of the procedures that were followed for the installation of targets off the M/V American Islander.

At designated positions in the range, multiple targets or target groups were installed. The targets in a group were attached together with approximately 1-meter sections of line. The lift line for the first, or uppermost, target was placed in the mechanical release mechanism.

The distance between adjacent targets was relatively short. The time required to maneuver the vessel between pre-determined adjacent target installation positions and recover the instrument package was utilized by the project personnel for setup of the next installation

Backup procedures to the installation process were available, but were not needed. Alternate procedures were thought of beforehand in case critical electronics on the deployment package failed for some reason. Target installations could have been performed by either: (1) lowering each target to the seafloor with a line rigged through the A-frame and slipping the line out when slack in the line was felt at the surface; or (2) releasing the target at the surface from a line rigged through the A-frame sheave and letting the target free fall through the water column to the seafloor. The deployment time for each of these could potentially have been faster, but control and placement accuracy would have been severely degraded. In both of the backup cases, an ROV system would be required to document the condition and position of the target on the seafloor. ROV operations can be very time consuming. The time needed to deploy the ROV and locate the target on the seafloor with the vehicle, added to the time needed to rig and deploy targets using the backup procedures, could add up to and possibly surpass the time required for the original installation approach. Other approaches, such as deploying the targets with small beacons attached for obtaining as-installed positions, or only obtaining the target positions and target/seafloor conditions during target recoveries, were considered either not cost effective or not technically acceptable. Precise as-installed positions and target/seafloor conditions were required to be documented to fairly evaluate the performance of the demonstrators. As-installed data was compared with data collected during target recoveries to determine if any changes had occurred. Any differences discovered in these data sets are discussed in the demonstration evaluation portion of this report, and were factored into the evaluation process.

Finally, selected targets installed from the M/V American Islander had skirted anchors attached. These anchors reduced the possibility of target movement after installation. The targets chosen to have the skirted anchors attached were the smaller and lighter of the targets, and were the targets installed in 10-meter to 15-meter water depths.

**Results -** A total of 217 targets were installed from the M/V American Islander. Of these, 204 were installed in water depths 10 meters and greater (offshore area of the STMC range), and 13 were installed in slightly less than 10 meters (nearshore). The average number of targets installed each day of operations was 17, and the maximum number installed in 1 day was 27. There was no downtime experienced during the installations due to weather or equipment failure. Operations were performed in up to slightly greater than SS3 conditions (Beaufort 3-4). The target installations were very controlled and extremely well documented. The deployment package functioned as designed, and the rate of target installations with the package was approximately 25 percent quicker than originally estimated. The package was stable while being towed between target positions up to a maximum of 5 knots. Because of the lack of downtime and the faster than expected rate of installations, installation operations from the M/V American Islander were completed 5 days ahead of schedule.

**C-2.3.2 Nearshore Target Installations and Anchoring (Divers).** Targets installed in the nearshore environment (water depths ranging from 3 meters to 10 meters) were to be done by divers operating out of small inflatable boats. These water depths were considered too shallow for the M/V American Islander, especially when considering the potential safety hazards involved with maneuvering the relatively large vessel near the surf zone.

As-installed position fixes and data logging were just as critical for the targets installed in the nearshore environment as they are for the targets installed offshore. A portable DGPS receiver was used on the inflatable boats. Selected targets in this area of the range had skirted anchors attached or were buried. Target burial discussions are included in a section to follow. All targets in 10 meters water depth or less were anchored with a Manta Ray type anchor. These anchors were driven into the seafloor to a depth of approximately 1 meter by the divers using a specially designed rod and hammer. A short piece of small diameter wire rope was attached between the target and the end of the anchor.

The weights of the targets that were installed by the divers were such that one or two persons could lift and lower them to the seafloor with a line. Each of the targets had a surface line and float attached to it for deployment.

At the start of each day, the divers loaded their gear and targets into the small inflatable boats as the M/V American Islander was slowly maneuvering to the position of the first target installation for the day. The divers then departed and commenced with target installation, anchoring, and burial operations.

**Results -** A total of 14 targets were installed and anchored by the NFESC divers in the nearshore area of the range. The instrumentation and hardware used by the divers for this effort functioned as planned. All installations were well documented, and were completed within the time allotted. A total of 1 day of weather downtime was experienced (two 1/2-day downtimes) during these operations. The divers were required to secure from diving before SS3 conditions were reached for safety reasons.

**C-2.3.3 Target Burials (Divers).** Targets were buried in the STMC range in water depths ranging from approximately 5 meters to 30 meters. All target burial operations were performed by the NFESC divers. Large targets (targets that could not be installed by the divers from the small inflatable boats) were installed from the M/V American Islander. These targets were relocated by the divers for burial by using position data collected on the M/V American Islander during installation. The positions were inputted into the diver portable DGPS system.

Targets were buried so that their heading did not change during the burial process. Sand was jetted from directly beneath the targets, resulting in an approximately straight down motion of the targets into the seafloor. The local seafloor area was groomed immediately after burial to leave as little as possible disturbance in the sediment. Heading data was collected by the divers just prior to burial. Position and water depth data was collected by the divers just prior to their return to the surface.

The burial depth of the targets varied randomly. Actual burial depths, along with other pertinent information, is contained in Appendix D. The burial depths were measured by the divers immediately prior to their return to the surface.

A Home Lite AP320 3 HP water pump with a jetting nozzle attached to the end of a fire hose was used by the divers for target burial. This small gasoline-powered system was operated from the larger of the two inflatable boats. Forty-five meters of hose was available on the surface boat.

**Results -** A total of 15 targets were buried by the NFESC divers in water depths ranging from approximately 5 to 30 meters. Burial depths of the targets ranged from 10 cm to 61 cm (0.6 meters). The instrumentation and hardware used by the divers for this effort functioned as planned, and the target burials were completed within the time allotted. No weather or equipment downtime was experienced during these operations.

**C-2.3.4 Wash Zone and Beach Target Installations (Divers).** These targets were transferred from the M/V American Islander to a 4-wheel drive truck at Port Allen. The truck was used to transport the targets from Port Allen to the beach area adjacent to the STMC range. The portable DGPS receiver was used to direct the truck to the beach directly shoreward of where a particular target was to be installed. These targets were both anchored and had a small diameter wire rope attached from them to the beach. The wire rope was used to relocate the targets during recovery operations.

A 30-meter antenna cable was attached between the portable DGPS receiver and the receiver's antenna. This was enough distance to allow the portable receiver to remain in the truck during the installation. The antenna was placed over the position of the target to collect the required data. The targets were installed in very shallow water or at a beach location. The installation of the wash zone targets was conducted during low wave height conditions and during low tide periods.

**Results -** A total of 15 wash zone targets were installed and anchored by the NFESC divers in water depths ranging from approximately 1 to 3 meters (wash zone), and 3 targets were installed and anchored on the beach (for airborne imaging system calibration). The instrumentation and hardware used by the divers for this effort functioned as planned and these installations were completed within the time allotted. No weather or equipment downtime was experienced during these operations.

## C-3. Unknown Target Remotely Operated Vehicle (ROV) Survey/Inspections

The original plan for the demonstration portion of the project included a quick-look assessment, including preliminary detected object position data, that was to be delivered by MMTC to NFESC immediately after the demonstration (while at the project site at the end of August 1995). Due to technical problems, MMTC was not able to deliver the quick-look report. This report was to contain a preliminary listing of the positions and classifications of the targets detected in the range. Preliminary position and classification data was not received at NFESC until several months after the completion of target recoveries. Therefore, unknown target survey/inspection operations were not conducted. These operations were planned, and should be conducted in any future UXO mapping and classification range work. With this in mind, the following section is included in this report for record.

It was anticipated that objects that NFESC did not install would be detected during the technology demonstration. A comparison of the MMTC quick-look report with the NFESC installed target database was expected to identify unknown (non NFESC installed) targets. These unknown targets could be actual ordnance accidentally left at the site during previous military exercises, seabed anomalies (natural), or some other types of man-made hardware. The unknown targets were planned to be relocated by NFESC using navigation data collected by the demonstration team. The planned objectives of the unknown target survey/inspection operations were to survey the areas where unknown target detections were made with an ROV, locate the unknown targets, and inspect the targets to determine their identity. The information collected with regard to the identity and positions of the unknown targets was to be factored into the final grading of the technology demonstration.

Table C-3 shows the planned summary schedule for the unknown target ROV survey/inspection operations.

Table C-3. Unknown Target ROV Survey/Inspection Planned Schedule

| LOCATION | RESP. ORG. | OPERATION | DAY COUNT |
|---|---|---|---|
| UNKNOWN TARGET SURVEY /INSPECTIONS | | | |
| Port Allen | NFESC | Setup/Move Eq. | 1 |
| Port Allen/Range | NFESC | Eq.Test/Shakedown | 1 |
| Port Allen/Range | NFESC | Demonstration | 5 |
| | | Total Days = | 7 |

As shown in the schedule, 5 full days were scheduled for these operations. The number of days planned was based on the assumption that the MMTC demonstration team would detect a maximum of 25 unknown targets. In the brief literature research effort that was performed by NFESC, no bathymetric or side-scan surveys were found to have been performed in the proposed STMC range area. However, very little debris was found in surveys performed in areas near the range. Also, discussions with PMRF personnel and Navy Underwater Construction Team divers familiar with the seafloor offshore PMRF indicated that the STMC range area was relatively clean of debris.

The following priority for unknown target surveys/inspections was set:

a. Unknown targets classified as ordnance by the demonstration team.
b. Unknown targets classified as non-ordnance but are suspect.
c. Unknown targets classified as non-ordnance but are thought to be man-made.
d. Unknown targets classified as non-ordnance and are not thought to be man-made.

## C-4. Range Recovery

Recovery of the STMC range was supervised and performed by NFESC. Recovery of the range consisted of target recoveries, DGPS shore station breakdown and packing, and the demobilization of the project vessel.

Table C-4 provides a summary schedule of events for the range recovery operations.

Table C-4 Range Recovery Operations Schedule Summary

| DATES (1995) | LOCATION | RESP. ORG. | OPERATION | DAY COUNT |
|---|---|---|---|---|
| STMC RANGE RECOVERY OPERATIONS | | | | |
| 08/19 | Port Allen | NFESC | Setup/Move Eq. | 1 |
| 08/20 - 09/09 | STMC Range | NFESC | Target Recoveries | 21 |
| 09/10 - 09/11 | Port Allen | NFESC | Prep. for Transit | 2 |
| 09/12 | Transit | NFESC | Transit to Oahu | 1 |
| 09/13 - 09/14 | Honolulu | NFESC | Demobilization | 2 |
| 09/15 | Honolulu | NFESC | Pack for Transp. | 1 |
| | | | Total Days = | 28 |

## C-4. 1 Target Recoveries

Target recoveries were conducted from the M/V American Islander using the NFESC ROV, from a LARC-V by divers, and from land/shallow water by divers (wash zone and beach targets). All diver recovery operations were performed independent of the recoveries conducted with the M/V American Islander. All targets weighing 91 kilograms and greater were recovered onto the M/V American Islander. This vessel also recovered all targets in water depths 27 meters and deeper (limited bottom time for SCUBA diving activities at these depths).

Targets recovered by the divers were periodically transferred to the M/V American Islander at the end of operation days.

Position, water depth, and heading data for each of the targets was again collected during the recovery operations.

**C-4.1.1 Recoveries Onto the M/V American Islander**. A depressor weight of approximately 226 kilograms was used with the NFESC ROV for target recoveries. The functions of the depressor weight were to: (1) reduce the degree of water current force acting on the vehicle's umbilical in the water column (the umbilical was attached to the depressor weight cable); (2) tend the vehicle's umbilical as straight down as possible to keep the umbilical away from the ship's propellers; (3) de-couple most of the motion of the ship from the vehicle (30 meters of umbilical between the vehicle and the depressor weight was slack in the water column); and (4) to serve as a hardware storage or attachment point for the vehicle while it was performing subsea work. Recovery line canisters and clips were mounted on the depressor weight.

Figure C-2 shows the ROV depressor weight with recovery line stuffing tubes attached to it. Each stuffing tube held 60 meters of line. After locating a target, the ROV was controlled to maneuver to the depressor weight. The three-function manipulator on the ROV was then used to grab a steel clip mounted on the weight. The depressor weight was temporarily set on the seafloor during this event. Each of the three recovery lines had a clip attached. The other ends of these lines were tied to eyes on the depressor weight.

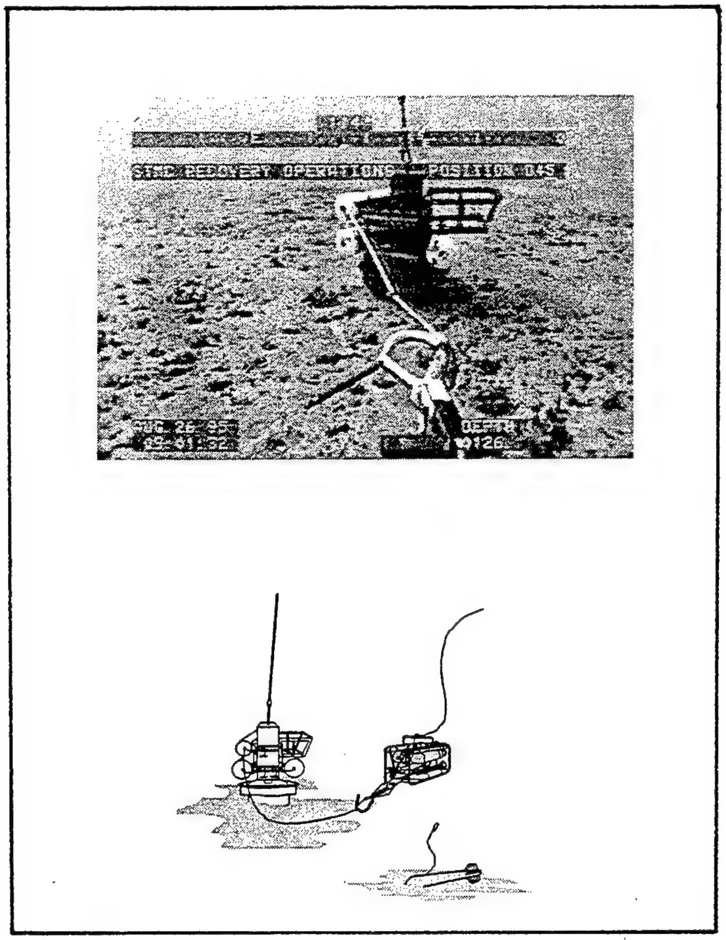


Figure C-2. ROV Depressor Weight with Stuffing Tubes Filled with 60-Meter Line

The ROV was then controlled to return to the target to clip the end of the recovery line to it. The recovery line pulled out of the stuffing tube as the ROV maneuvered. Once the line was attached to the target, the clip was released by the ROV, and the depressor weight and vehicle were recovered to the surface. At the water's surface, while the ROV was controlled to hold position away from the vessel and the depressor weight was held against the side of the vessel, the load of the target was transferred from the depressor weight to a line on the vessel's deck winch. This line ran through a sheave on the vessel's A-frame. The vessel's deck winch and A-frame were then used to lift the target off the seafloor and recover it onto the deck of the vessel. Immediately after the target weight was transferred to the deck winch, the depressor weight and ROV descended to continue target recoveries. After three recoveries, the depressor weight was recovered and the expended stuffing tubes were replaced with tubs filled with line.

**Results -** A total of 103 targets were recovered onto the M/V American Islander. Each of the targets were found within a few meters (within the errors of the surface and subsurface navigation systems used) of their as-installed positions. However, one target was not located. A 50-meter diameter search in the areas surrounding the as-installed position of this target was

performed with the ROV. It is believed that the target was located at a water depth too deep (37 meters) to be moved by the wave action observed during the time between the installation and recovery operations, and the water current velocities observed during subsea work performed in the general area of this target are believed to have been too low to have moved it. All other targets (even items much less in weight) were found very quickly, and very close to the positions that they were installed at. Therefore, it is suspected that the target that was not located was moved great distances or recovered to the surface by fishing or small boat (non-project) anchoring activities. A number of small boats were observed in the range area during the course of the project work.

The maximum number of targets recovered in 1 day was 15, and the average number recovered per day was 6. The average number of targets recovered per day was within the range estimated prior to the start of the operations (estimated 5 to 10 per day). Two days of equipment failure and one day of weather downtime were experienced during these operations. Target recovery operations were able to be conducted in up to SS3 conditions.

Note: PMRF, the local Coast Guard, and the Navy Explosive Ordnance Disposal (EOD) unit responsible for the STMC range area were notified of the project activities. A letter containing a description of each lost target, the last known positions, and the last date that the targets were observed was sent to PMRF immediately following the recovery operations. PMRF personnel will periodically search the beaches adjacent to where the STMC range was installed for the targets. NFESC will be notified if any targets are found.

**C-4.1.2 Wash Zone and Beach Target Recovery Operations (Divers).** Due to the dynamic environment that these targets are installed in, these were the first targets that were attempted to be recovered by the divers. The portable DGPS was used to guide the dive personnel to a location on the beach directly shoreward of the target to be recovered. The beach marker stake for the target was located and shovels were then used to dig the wire rope attaching the marker to the target from the sand. The water depth of the target was verified and the portable DGPS antenna was held over the location of the target as position data was recorded. The target anchor was either pulled or dug out of the sand to retrieve the target. The recovery of these items was conducted during low wave height conditions and during low tide periods, whenever possible.

**Results -** Of the 15 wash zone targets that were installed, eight were recovered. Seven targets could not be recovered because they had been buried by sedimentary processes to a depth greater than 3 meters. The burial of these targets occurred in a matter of only 2 weeks. Only approximately 1 meter of sand transported onto the local beaches was anticipated. According to literature referenced and persons contacted that were knowledgeable with the sedimentary processes off Kauai, the observed amount of sediment moved onto the beaches of PMRF was very unusual for the time of year that the project work was performed. Three attempts were made to recover the buried wash zone targets, each attempt at least 5 days apart. During each attempt, once the recovery personnel reached the water table (up to 3 meters deep in sand) and realized that they still needed to dig another 0.5 to 1.5 meters, the recovery attempt for that

particular target was discontinued. The personnel did not have the proper equipment to safely dig below the water table. The three targets installed and anchored on the beach for calibration of the airborne imaging system were recovered without mishap. No weather or equipment downtime was experienced.

The seven wash zone targets that were not recovered were also included in the letter to PMRF mentioned in the previous section. These targets are still secured to shore with wire rope. It is anticipated that as soon as winter storm wave action moves sediment off the local beaches, the PMRF personnel will be able to easily locate and recover these targets.

**C-4.1.3 Diver Target Recovery Operations in Water Depths Ranging from 5 to 30 Meters**. A LARC-V and a small inflatable boat were used to support these recoveries. The small inflatable boats were used as diver deployment and chase boats. A small aluminum davit was mounted onto the deck of the LARC-V. An electric winch on the davit was used to hoist the targets from the seafloor to the deck of the LARK. Buried targets were unburied using the same hardware that they were buried with. Sediment was jetted off of the top of the targets. After the targets were removed from the depression in the seafloor, the depression was again filled with sediment using the jetting system and by hand.

Prior to recovery, position, water depth and target heading data was collected. Position data was taken at the surface, off of plumbed surface floats. The portable DGPS receiver used during target installations was again used to obtain position data.

**Results** - A total of 127 targets were recovered onto the LARC-V by divers. Only recoveries of items weighing less than 91 kilograms and located in water depths less than 27 meters were attempted. As with the recoveries onto the M/V American Islander, each of these targets were found within a few meters of their as-installed positions. Three targets were not located during these operations. A 50-meter diameter search in the areas surrounding the as-installed positions of the targets was performed with divers. All other seafloor resting targets in the area that the divers performed recoveries were found very quickly, and very close to the positions that they were installed at. Also, the targets that were not located had been anchored to the seafloor. Either the wire rope securing the targets to their anchors failed and the targets were moved by water currents or wave action, or the lost targets were moved great distances and/or recovered to the surface by fishing or small boat (non-project) anchoring activities.

The maximum number of targets recovered in 1 day by the divers was 20, and the average number recovered per day was 10. The average number of targets recovered per day was exactly the number estimated prior to the start of the operations. During the subsea target recovery period, the divers also unburied 15 targets. One day of weather downtime was experienced during these operations. Operations were able to be conducted in up to just less than SS3 conditions.

The three targets that were not recovered were also included in the letter to PMRF mentioned above.

**C-4.1.4 DGPS Shore Station Breakdown and Packing.** On the day that the M/V American Islander made transit from Kauai to Honolulu, NFESC project personnel broke down and packed the DGPS shore station at the Bore Sight Tower on PMRF. These personnel brought the shore station equipment with them on their flight from Kauai to Honolulu. They met the ship for demobilization on the following day.

**C-4.1.5 Vessel Demobilization.** Demobilization of the M/V American Islander was performed in Honolulu, Hawaii, at the home pier space of the M/V American Islander. American Workboats provided demobilization personnel and equipment support. All of the diver support equipment, except for the LARC-Vs, were loaded onto the M/V American Islander prior to the vessel's departure from Kauai. The LARC-Vs were transported back to Port Hueneme, California on a commercial container ship.

## C-5. Offshore Support Platforms And Equipment

### C-5.1 Support Platforms

Three types of offshore support platforms were used during the STMC range activities: (1) a 30-meter long workboat named the motor vessel (M/V) American Islander; (2) small inflatable boats; and (3) United States Navy LARC-V amphibious vehicles.

**C-5.1.1 M/V American Islander.** This vessel supported target installation, demonstration, and target recovery activities. Figures C-3 and C-4 are pictures of the vessel, showing bow and stern views.

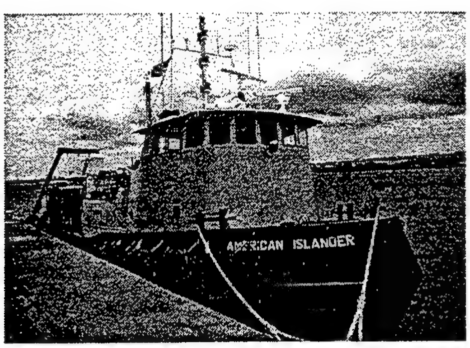



Figure C-3. Bow View of the M/V American Islander

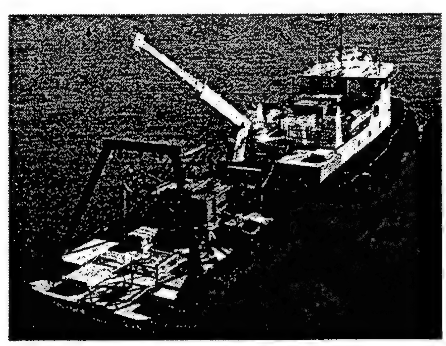


Figure C-4. Stern View of the M/V American Islander

The M/V American Islander had the following specifications and onboard equipment:

| | |
|---|---|
| Year Built: | 1970 (complete rebuild in 1994) |
| Dimensions: | 30 Meters x 7.3 Meters x 3.7 Meters |
| Available Deck Space: | 102 Square Meters |
| Engines: | 2 GM Detroit Diesels, Model V-16-71 |
| Generators: | 2-30 kW, 110/220 Volts, GM Detroit Diesels, Model 3-71 |
| Speed: | 12 Knots |
| Horse Power: | 1,000 HP |
| Fuel Capacity: | 97,836 Liters |
| Fuel Consumption: | 125 Liters/Hour |
| Hydraulic A-Frame: | 20 Ton Articulating |
| Hydraulic Crane: | 15 Ton Hydraulic |
| Deck Winch: | Hydraulic Single Drum with Single Capstan; Capacity 457 Meter of 0.95 Centimeter Diameter Wire; Line Pull at 25 RPM 11,364 Kilograms at 12.5 RPM 22,727 Kilograms |
| Electronics: | Radar, Single Side Band Radio, VHF Radios, Private UHF Radio, Auto Pilot, GPS, 50 MHz Depth Sounder |
| Accommodations: | USCG Certified to Carry 40 Passengers plus 4 Crew, Sleeps 20 |
| Gross Tons: | 98 |

**C-5.1.2 Small Inflatable Boats.** Two small inflatable boats powered by 40-horsepower outboard engines were used during the range operations to support diving activities. Diver deployment, recovery, and monitoring was conducted from a 5.8-meter long inflatable Zodiac. The second inflatable boat, a 4.6-meter long Zodiac, was used to carry selected diving support equipment and functioned as a diver chase boat. NFESC dive personnel operated and maintained these boats.

**C-5.1.3 Navy LARC-V Amphibious Vehicles**. Two U.S. Navy LARC-V amphibious vehicles were used by NFESC dive personnel to support target recovery operations. These aluminum vehicles were designed by the Navy to carry cargo from an offshore supply ship to a beach or inland area during amphibious operations. The LARC-Vs were modified with a deck-mounted davit and wire rope winch for the range work. The davit and winch were used to lift targets from the seafloor to the deck of the LARC-V. Figure C-5 shows the divers alongside a LARC-V in the 5.8-meter long inflatable. The target recovery davit can be seen at the center of the figure.

The LARC-V has the following specifications:

| | |
|---|---|
| Manufacturer: | Consolidated Diesel Corporation |
| Dimensions: | 10.7 M x 3 M x 3.1 M |
| Weight: | 5 Tons |
| Deck Space: | 14.6 Square Meters |
| Payload: | 4,545 Kilograms |
| Engines: | Diesel (wheel drive and single propeller) |
| Fed. Stock #: | 1930-710-5728 |
| Speed: | Land 21.5 mph, Water 8.5 Knots |
| Davit: | 545 Kilogram Maximum Lift |

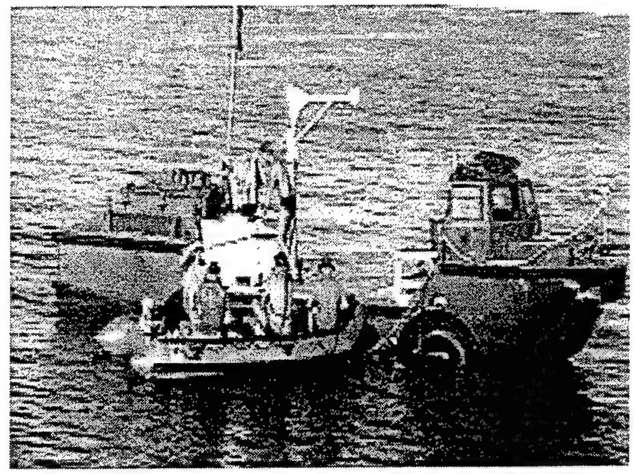


Figure C-5. LARC-V and 5.8-Meter Inflatable

Two LARC-Vs were on-site, but only one was used at a time. The second LARC-V remained on land as a backup. Navy Underwater Construction Team - One (UCT-One) personnel, based in Port Hueneme, California, conducted cable repair and maintenance activities on the PMRF BESURE range with the vehicles before the STMC range target recovery operations began. The UCTs transported the vehicles from California to Kauai in support of their project, and turned over the use of the vehicles to the NFESC divers immediately following completion of their work. The NFESC dive team arranged to transport the vehicles back to California after the vehicles were used for the STMC range recovery operations. NFESC operated and maintained these vehicles during the STMC range effort.

### C-5.2 Navigation and Subsea Data Collection Systems

**C-5.2.1 Navigation On the M/V American Islander.** All of the navigation and data collection systems used on this vessel were owned by NFESC, and were operated by NFESC or Pelagos Corporation personnel.

The primary surface navigation system used on the M/V American Islander during the range operations was a Novatel model #311R global positioning system (GPS) receiver, used in differential mode (DGPS). The backup surface navigation system was a Trimble model 4000RL/DL II GPS receiver, also used in differential mode. A Nautronix S04 Ultra Short Baseline (USBL) Acoustic Tracking System (ATS) was the primary system used for sub-surface navigation and object tracking. A Trackpoint II USBL system served as backup to the Nautronix. A subsea USBL acoustic mini-beacon served as a responder on a NFESC target deployment package during installations, and on a NFESC remotely operated vehicle (ROV) used for target recoveries. Acoustic USBL beacons were also used on demonstration hardware for subsea tracking. A KVH model 314AC Azimuth digital compass provided ship heading information, and fluxgate compasses on the target deployment package and ROV were used for obtaining target orientation data. An vessel-mounted ODEM Echotrac precision fathometer provided data regarding the water depth below the vessel, and depth transducers on the target

deployment package and ROV provided water depth data for these systems. Pelagos Winfrog integrated navigation software was used on a project computer to integrate surface navigation, subsurface navigation and tracking, and compass data for real-time display and documentation.

Navigation and target spreadsheet data were saved to computer hard drive and diskettes periodically during each day of operations. A Hewlett Packard Think Jet printer was used to make hard copies of the navigation and spreadsheet data, and a plotter capable of plotting 27.9-cm by 43.2-cm (11-inch by 17 inch - B size) sheets was available to plot integrated navigation in real-time, and to construct pre- and post-plots of range navigation data.

**C-5.2 On the Shallow Water Inflatable Support Boats and LARC-Vs**
The navigation and subsea data collection systems used on these support platforms were owned by NFESC, and were operated by NFESC dive locker personnel.

A Motorola Model #LGT1000 GPS receiver was set up as a mobile station and used in "differential mode" for offshore operations performed from the small inflatable boats and LARC-Vs in the shallow water areas of the STMC range. The receiver, support instrumentation, and power source (small 12-volt battery) were placed into a backpack to enable the system to be transported by one person. A 30-meter cable was attached between the GPS receiver and its antenna. The GPS antenna was held by one person over a plumbed surface float attached to an installed target while a second person operated the Motorola Model #LGT1000 to collect data. Water depth and target orientation data were collected in-situ by divers using diver depth gages and compasses.

**C-5.3 DGPS Base Station**
The primary differential base station was a Novatel Model #3111R GPS receiver, set up in "fixed position" mode and outputting pseudorange corrections in the standard RTCM-104 format to a Teledesign Model #TSI9600 radio modem. The backup differential base station consisted of a Trimble 4000 Marine Surveyor (MS) receiver, set up in "fixed position" mode and outputting pseudorange corrections in the standard RTCM-104 format to a motorola DATARADIO and model IGD BDLC-91 modem. Identical radios/modems were used with the M/V American Islander and diver shallow water support boat mobile stations to receive the pseudorange corrections. The base station for the DGPS systems was set up adjacent to a surveyed brass disk on the pad for the PMRF Bore Sight Tower. Offsets from the GPS antenna to the brass disk were measured and accounted for in the setup of the shore station receiver. The brass disk survey marker at the base of the tower has the following geodetic position (Ref 22):

| *Geodetic Position (WGS-84)* | *UTM Position* |
|---|---|
| Lat: 22.0094467° | X: 419,959.711 E |
| Long: -159.7754618° | Y: 2,434,075.571 N |
| Height (MSL): 3.807 meters | |

### C-5.4 Data Collection Responsibilities

Table C-5 lists the data collection responsibilities for the STMC range operations. The table includes the type of data that was collected, the organization responsible for the collection and retention of the data (data coordinator), which at-sea operation it was collected in support of, the disposition of the data, and the primary system or technique used to obtain it.

Table C-5. Data Collection Responsibilities

| | TYPE OF DATA COLLECTED | DATA COORDINATOR | STMC OPERATION | FINAL DISPOSITION OF THE DATA | SYSTEM OR TECHNIQUE USED |
|---|---|---|---|---|---|
| 1. | Vessel Position | NFESC | Range Establishment & Recovery | Integ. Nav. Computer | DGPS |
| | | MMTC Team | Technology Demonstration | MMTC Computer | DGPS |
| 2. | Vessel Heading | NFESC | Range Establishment & Recovery | Integ. Nav. Computer | Digital Compass |
| | | MMTC Team | Technology Demonstration | MMTC Computer | Digital Compass |
| 3. | Integrated Nav. | NFESC | Range Establishment & Recovery | Disk/Display | Nav. Computer |
| | | MMTC Team | Technology Demonstration | Disk/Display | MMTC Computer |
| 4. | Target Position and Heading (Subsurf.) | NFESC | Range Establishment & Recovery | Integ. Nav. Computer | Subsurf. Nav./Deploy. Package/ROV/Divers |
| | | MMTC Team | Technology Demonstration | MMTC Computer | Subsurf. Nav./Detection Systems |
| 5. | Target Water Depth | NFESC | Range Establishment & Recovery | Integ. Nav. Computer | Fathometer/Deploy. Package/ROV/Divers |
| | | MMTC Team | Technology Demonstration | MMTC Computer | Subsurface Nav./Detection Systems |
| 6. | Target 35mm Stills (Subsurface) | NFESC | Range Establishment & Recovery | Label/List/Develop/ File | Deployment Package/ROV/Divers |
| 7. | Target Video (Subsurface) | NFESC | Range Establishment & Recovery | Label/List/File | Deployment Package/ROV/Divers |
| 8. | Surface Video | NFESC | Range Establishment & Recovery | Label/List/File | Hand-Held Video Camera |
| | | MMTC Team | Technology Demonstration | Label/List/File | Hand-Held Video Camera |
| 9. | Wind Speed and Direction | NFESC | Range Establishment & Recovery | Integ. Nav. Computer | Observation/Log |
| | | MMTC Team | Technology Demonstration | MMTC Notes | Observation/Log |
| 10. | Sea State | NFESC | Range Establishment & Recovery | Integ. Nav. Computer | Observation/Log |
| | | MMTC Team | Technology Demonstration | MMTC Notes | Observation/Log |
| 11. | General Notes | NFESC | Range Establishment & Recovery | Integ. Nav. Computer | Observation/Log |
| | | MMTC Team | Technology Demonstration | MMTC Notes | Observation/Log |

### C-5.5 Diving Operations

The NFESC Navy dive locker supervised and performed all diving. Self-Contained Underwater Breathing Apparatus (SCUBA) was used (no surface-supplied diving conducted). Diver deployment, recovery, and monitoring were performed from the two inflatable boats described in Section 6.1.2. An AGA Divator II Full Face Mask (FFM) communication system (Navy MK20 Mod 0) was used for communications between the divers and the surface diver support boat while subsea work was in progress. All of the NFESC dive equipment, including the two small inflatable boats and an air compressor, were mobilized on the M/V American Islander in Honolulu prior to the start of the range activities. During target installation operations, the divers used the M/V American Islander for gear storage, to fill SCUBA bottles, and as a field equipment repair platform. During target recovery operations, the primary diver support platforms were LARC-Vs. The diver's air compressor, spare dive equipment, and tools were stored at a dive facility on PMRF during this phase of the work. The two inflatable boats were again used to deploy and recover divers, and as diver chase boats. Both LARC-Vs were stored at the diver support facility on PMRF between operation days.

### C-5.6 Remotely Operated Vehicle (ROV) System Description

An ROV system was used for target recovery operations conducted off the M/V American Islander. The ROV system used was the NFESC owned and operated Deep Ocean Engineering (D.O.E.) PHANTOM DHD2+. It is a 610-meter (2,000-foot) water depth capable system. The vehicle was configured with the following equipment: a forward looking high resolution color video camera (capable of tilting ±90 degrees) and 2 lamps (2 @ 250 watts); an aft looking high resolution color video camera and one lamp (150-watt lamp); a 35-mm still camera and strobe; a compact color imaging sonar (675 KHz); a three-function manipulator; a sub-surface acoustic responder (for sub-surface navigation and tracking); four horizontal thrusters; a vertical thruster; a lateral thruster; a depth gauge; and a fluxgate compass. The controls, video monitors, and video recorders for the ROV system were located in a van mobilized on the back deck of the M/V American Islander. The vehicle was operated from within this van. Both Hi-8-mm and VHS video formats were recorded for video documentation.

An NFESC owned ROV platform was also mobilized on the back deck of the vessel. A hydraulic articulating A-frame and wire rope winch mounted on the platform were used to support ROV operations. The ROV was deployed from, and recovered back onto, the platform using the articulating A-frame. The hydraulic winch was used for deploying and recovering the vehicle's depressor weight.

## C-6. Detailed Schedules and Procedures

### C-6.1 Range Establishment

Table C-6 gives the detailed schedule for the establishment of the STMC range.

Table C-6. Detailed Range Establishment Schedule

| DATE (1995) | WK. DAY | SHIP LOCATION | RESP. ORG. | OPERATION | COMMENTS |
|---|---|---|---|---|---|
| 07/06 | Thurs. | Honolulu | NFESC | Mobilization | Mobilization |
| 07/07 | Fri. | Honolulu | NFESC | Mobilization | Mobilization |
| 07/08 | Sat. | Transit | NFESC | Transit to Kauai | Transit to Kauai/Personnel Fly/DGPS |
| 07/09 | Sun. | Port Allen/Range | NFESC | Setup/Test | Setup/Dry and Wet Test Systems |
| 07/10 | Mon. | STMC Range | NFESC | Target Instal. | Offshore Installations |
| 07/11 | Tues. | STMC Range | NFESC | Target Instal. | Offshore Installations |
| 07/12 | Wed. | STMC Range | NFESC | Target Instal. | Offshore Installations |
| 07/13 | Thurs. | STMC Range | NFESC | Target Instal. | Offshore Installations |
| 07/14 | Fri. | STMC Range | NFESC | Target Instal. | Offshore Installations |
| 07/15 | Sat. | Port Allen | NFESC | Data Ck/Anal. | Data Check/Manipulation/Analysis |
| 07/16 | Sun. | STMC Range | NFESC | Target Instal. | Offshore Installations |
| 07/17 | Mon. | STMC Range | NFESC | Target Instal. | Installations/Divers Arrive on Kauai |
| 07/18 | Tues. | STMC Range | NFESC | Target Instal. | Offshore Installations |
| 07/19 | Wed. | STMC Range | NFESC | Target Instal. | Installations and Diver Burial/Shallow |
| 07/20 | Thurs. | STMC Range | NFESC | Target Instal. | Installations and Diver Burial/Shallow |
| 07/21 | Fri. | STMC Range | NFESC | Target Instal. | Installations and Diver Burial/Shallow |
| 07/22 | Sat. | STMC Range | NFESC | Target Instal. | Installations and Diver Burial/Shallow |
| 07/23 | Sun. | Port Allen | NFESC | Day Off | Day Off/Data Check/Manip./Analysis |
| 07/24 | Mon. | STMC Range | NFESC | Target Instal. | Installations and Diver Burial/Shallow |
| 07/25 | Tues. | Range/Port Allen | NFESC | Instal./Prep. | Instal./Prep. for Transfer to MMTC |

**C-6.1.1 Offshore Target Installations (M/V American Islander).** The following procedures were performed for target installations off the M/V American Islander:

a. The vessel was slowly maneuvered to the predetermined position of the target to be installed. Once at the desired position, the vessel was controlled to hold station. The captain of the vessel was guided to the predetermined installation position by viewing an integrated navigation display monitor on the bridge. Communications between the bridge, back deck, and the NFESC instrumentation van were established and used as required.

b. While the vessel was maneuvering, the A-frame was moved slightly aft of the vessel's stern. This placed the A-frame structure clear of the area that the crane was required to reach for placement of the target on the back deck. The target deployment package was already resting on the deck near the stern. The deployment package cable was pre-rigged from the deployment winch, through a sheave attached to the A-frame, and connected to the package.

c. While the vessel was holding station, the targets to be installed were placed on the aft deck with the vessel's crane. The targets were placed just aft of the deployment package. All of the targets were secured to or stored in custom pallets. The targets remained in their storage pallets

until they were ready to be attached to the mechanical release mechanism on the deployment package. Therefore, targets were not allowed to inadvertently roll or move around on the deck.

d. The targets were then slid under the deployment package. The deployment package had four adjustable legs that allowed it to be set over the targets, with enough room remaining under the package for attachment of the mechanical release mechanisms. Each target had either one or two lifting lines attached to it, depending upon the size and weight of the target. These lifting lines were used to pull the targets under the deployment package. A large crowbar was used to assist with the moving of the larger targets. Eyes at the bitter ends of the target lifting lines were attached to the mechanical release mechanism. Two tag lines were slipped through steel eyes welded to the deployment package and the tag lines secured the deployment package to the deck for safety while the targets were being moved about the deck.

e. The deployment package and target were lifted off the back deck with the deployment package winch while the package was held securely with the tag lines.

f. The hardware was moved aft over the water with the A-frame, and lowered into the water with the winch. The tag lines were slipped off the deployment package as the package left the ocean surface.

g. The hardware was lowered to the seafloor while the vessel held station.

h. When the seafloor was in view on the deployment package video camera, the NFESC instrument operator instructed the winch operator to stop cable deployment.

i. The NFESC instrument operator then instructed the winch operator to slowly deploy cable until the motion of the target, due to ocean swells, brought the target within a couple feet of the seafloor at the lowest point. The instrument package video camera and altimeter were used by the instrument operator to determine when to cease cable deployment.

j. When the installation position had been verified by the navigation specialist, and the surrounding seafloor condition was deemed acceptable by the NFESC instrument operator, the instrument package mechanical release mechanism was triggered to release a target. The release was timed to coincide with when the vessel was in the trough of a swell to reduce the distance that the target fell to the seafloor. At the moment of release, the logging of all navigation and other systems was performed by the navigation specialist and the NFESC instrument operator.

k. Immediately following release of the target, the NFESC instrument operator instructed the winch operator to recover the deployment package, and video and 35-mm stills were taken of the target in-situ.

l. The deployment package was recovered to approximately 10 meters off the seafloor as the M/V American Islander slowly maneuvered to the next installation position.

To recover the deployment package after both targets were released, the following steps were performed:

a. The deployment package was recovered to a water depth of approximately 3 meters as the vessel was controlled to hold station. The bridge and back deck were then notified that the deployment package was at the surface and ready to be recovered.

b. The deployment package was lifted out of the ocean with the deck winch, and moved inboard with the A-frame. Tag lines were immediately slipped through the steel eyes on the package as it was slowly moved inboard. When the package was at the desired position for lowering to the deck, the motion of the A-frame was stopped, and the package was lowered onto the back deck with the deck winch. The deployment package was then secured on the deck for the attachment of the next target set.

**C-6.1.2 Nearshore Target Installations and Anchoring (Divers).** The following procedures were performed to install and anchor targets from small inflatable boats in the STMC range nearshore environment:

a. The small boats anchored at the predetermined installation position for the target to be installed. With mask, fins and snorkel only, a diver viewed the seafloor in the immediate area. The water depth was approximately 10 meters or less.

b. One end of a 0.95-cm diameter nylon line was attached to the recovery line on the target as a diver inspected the seafloor. The 0.95-cm diameter line served as a lowering line for the target. A 15.24-cm diameter surface float was then attached to the other end of the lowering line. The lowering line was cut to a length that equaled the water depth plus a few meters.

c. If the seafloor condition was satisfactory (no delicate marine life or man made objects that may entangle the target), the target was ready to be overboarded. If the seafloor condition was not satisfactory, the inflatable boat anchors were recovered, moved approximately 10 meters from the unsatisfactory object or area in any direction, and step #1 was performed again. The majority of the seafloor in the nearshore area was covered with sand only, and there were no man-made objects laying on the bottom.

d. The target was slowly lowered to the seafloor. Slack in the lowering line indicated that the target was on the seafloor.

e. Divers descended to the target. A Manta Ray anchor was already attached to the target with a short length of small diameter wire rope. The divers hammered the anchor approximately 1 meter into the seafloor using a steel rod and hammer specially fabricated for the task. The steel rod and hammer were lowered from one of the small boats upon request by the divers.

f. Divers documented the condition of the target and the surrounding seafloor with video.

g. Divers pulled on the lowering line to plumb the line, and communicated to the surface that the lowering line was tight.

h. The DGPS receiver antenna was then held over the plumbed target surface buoy and a position fix was taken. Target water depth and heading information were then collected.

i. Divers signaled to the surface that all of the required data had been collected.

j. Divers disconnected the lowering line from the target and returned to the surface.

This completed one nearshore target installation and anchoring operation. Steps a through j were repeated for each target installed in this environment.

**C-6.1.3 Target Burials (Divers).** The following procedures were performed by the NFESC divers to bury targets:

a. If the target was installed by the divers, the procedures for installation and position fixes in the previous section were followed. The only difference was that no target anchor was attached. If the target was already installed by the M/V American Islander, target burial began by locating the target and anchoring the small inflatable boats.

b. Divers entered the water and were handed the nozzle end of the burial system. They then followed the target lowering line down to the target.

c. After arriving at the target, the divers recorded target heading data.

d. Divers then instructed the surface personnel to start the water pump.

e. When target burial was completed, the divers signaled to the surface to stop the water pump and recover the hose/nozzle. The short recovery line attached to the target served as an indication of burial depth. Also, the eye at the end of this line remained above the surface of the seafloor after burial and was used during recovery operations to find and recover the target.

f. The sediment over the target was then groomed to look as similar as possible to the surrounding seafloor. It was desired to have as little sediment disturbance as possible in the burial area evident after the burial effort.

g. Divers measured the depth of burial with a pre-marked rod. The rod was pushed through the sand until it hit the target at several locations. Target burial depth information was logged as measurements were taken.

h. Divers pulled the lowering line tight and signaled to the surface to record position data. At this time the divers also recorded water depth data.

i. Divers untied the lowering line from the target, and recorded video of the target location and the surrounding seafloor before returning to the surface.

This completed one cycle of target burial operations. Steps a through i were repeated for subsequent target burials.

**C-6.1.4 Wash Zone and Beach Target Installations (Divers).** The following procedures were performed to install, anchor, and document the position of these targets:

a. The project truck was parked as close to the waterline as possible. One person carried a Manta Ray anchor and the wire rope that was taken to shore, another the Manta Ray anchor rod and hammer, and a third person carried the antenna to the portable DGPS receiver. A Manta Ray anchor and the shore line were already attached to the target.

b. When at the desired water depth and position, the target was placed on the seafloor (or beach) and the Manta Ray anchor was driven into the seafloor/beach. The person that carried the target out held the wire rope while the anchor was driven into the seafloor. Once this person set the target on the seafloor/beach, he placed his foot on the target to reduce the possibility of movement.

c. As soon as the anchor emplacement was completed, the shore wire rope was held tight, straight up from the target, and the portable DGPS receiver was positioned directly above the target (as indicated by the direction of tend of the wire rope).

d. Personnel at the receiver were signaled to record the target's position. Several fixes were taken.

e. The installation personnel then deployed wire rope as they walked to the perimeter of the beach.

f. The wire rope was run across the beach and into brush located at the perimeter of the beach (directly inshore from the target). A stake and flag were attached to the end of the wire rope and hidden in the brush.

g. The wire rope was buried in the beach sand with shovels and an attempt was made to remove any indications of sand displacement. This was done with a rake or with broken pieces of brush found near the beach. The wind also helped remove any traces of burial after a few days.

It was important to conceal the shore line as best as possible because these targets were searched for using an airborne optical system. Data collected with the system was analyzed to determine

any unusual disturbances or objects in the nearshore water and wash zone. The optical system was advertised to be able to pick up indications of recent sand disturbances on the beach. This would be especially true if disturbances were in a straight line.

This completed one cycle of wash zone/beach target installation operations. Steps a through g were repeated for subsequent installations.

### C-6.2 Demonstration Field Operations

**C-6.2.1 Demonstration Detailed Schedule**. Table C-7 gives the detailed schedule for the STMC range demonstration activities. The detailed procedures for the demonstration operations will be provided in the MMTC/OBD final report.

Table C-7. Detailed Demonstration Schedule

| DATE (1995) | WK. DAY | SHIP LOCATION | RESP. ORG. | OPERATION | COMMENTS |
|---|---|---|---|---|---|
| 07/30 | Sun. | Port Allen | MMTC | Load/Setup Eq. | Equipment Load/Setup |
| 07/31 | Mon. | Port Allen | MMTC | Setup/Test Eq. | Equipment Setup and Test |
| 08/01 | Tues. | Port Allen | MMTC | Repair/Test | Side-Scan Sonar Repair and Test |
| 08/02 | Wed. | Port Allen | MMTC | Repair/Test | Side-Scan Sonar Repair and Test |
| 08/03 | Thurs. | STMC Range | MMTC | Demonstration | Phase 2 - SeaBat Bathymetry Survey |
| 08/04 | Fri. | STMC Range | MMTC | Demonstration | Phase 2 - SeaBat Bathymetry Survey |
| 08/05 | Sat. | Port Allen | MMTC | Analysis/Setup | Map Potential Targets/Reconfig. Eq. |
| 08/06 | Sun. | Port Allen | MMTC | Analysis/Setup | Map Potential Targets/Reconfig. Eq. |
| 08/07 | Mon. | Port Allen | MMTC | Analysis/Setup | Map Potential Targets/Reconfig. Eq. |
| 08/08 | Tues. | STMC Range | MMTC | Demonstration | Phase 3 - Cal. Area and Seismic |
| 08/09 | Wed. | STMC Range | MMTC | Demonstration | Phase 3 - Cal. Area and Seismic |
| 08/10 | Thurs. | STMC Range | MMTC | Demonstration | Phase 3 - Cal. Area and Seismic |
| 08/11 | Fri. | Port Allen | MMTC | Analysis/Repair | Post Process Data/Repair Side Scan |
| 08/12 | Sat. | Port Allen | MMTC | Analysis/Repair | Post Process Data/Repair Side Scan |
| 08/13 | Sun. | Port Allen | MMTC | Analysis/Repair | Post Process Data/Repair Side Scan |
| 08/14 | Mon. | Port Allen | MMTC | Analysis/Repair | Post Process Data/Repair Side Scan |
| 08/15 | Tues. | Port Allen | MMTC | Analysis/Repair | Post Process Data/Repair Side Scan |
| 08/16 | Wed. | STMC Range | MMTC | Demonstration | Phase 4 - Side-Scan Survey |
| 08/17 | Thurs. | STMC Range | MMTC | Demonstration | Phase 4 - Side-Scan Survey |
| 08/18 | Fri. | Port Allen | MMTC | Pack/Secure | Pack/Secure Hardware for Transp. |

### C-6.3 Planned Unknown Target ROV Survey/Inspection Operations

**C-6.3.1 Unknown Target ROV Survey/Inspection Detailed Planned Schedule**. Table C-8 gives the detailed schedule planned for the unknown target ROV survey/inspection activities. As described in the main body of the report, the unknown target survey was not actually conducted because of timing of the demonstrator results.

Table C-8. Detailed Planned Unknown Target ROV Survey/Inspection Schedule

| DAY | SHIP LOCATION | RESP. ORG. | OPERATION | COMMENTS |
|---|---|---|---|---|
| 1 | Port Allen | NFESC | Eq. Reconfig. | MMTC Eq. Offload,NFESC Move Eq. |
| 2 | Port Allen/Range | NFESC | Shakedown | ROV/Nav Shakedown and Survey |
| 3 | STMC Range | NFESC | Survey/Insp. | ROV Survey and Inspection Ops |
| 4 | STMC Range | NFESC | Survey/Insp. | ROV Survey and Inspection Ops |
| 5 | STMC Range | NFESC | Survey/Insp. | ROV Survey and Inspection Ops |
| 6 | STMC Range | NFESC | Survey/Insp. | ROV Survey and Inspection Ops |
| 7 | STMC Range | NFESC | Survey/Insp. | ROV Survey and Inspection Ops |

**C-6.3.2 Planned Unknown Target ROV Survey/Inspection Planned Procedures.** The following steps were planned to be followed to survey and inspect unknown targets from the M/V American Islander with the NFESC ROV system:

a. The M/V American Islander would be maneuvered to the unknown target position and controlled to hold station.

b. The ROV would then be deployed.

c. The ROV would be controlled to survey the local area for the unknown target. The ROV sonar and video camera would be used for the search/survey effort. An expanding box search pattern would be followed until the unknown target was located.

d. When the unknown target was located, it would be inspected at a distance to determine if the object was actual ordnance (not installed by NFESC). If the object was suspected to be ordnance, a video tape recording, 35-mm still photograph, and a position fix would be recorded from the present location of the ROV. The vehicle would then be controlled to return to the surface. If the object was determined to be non-ordnance or an object that was deployed by NFESC and moved, the inspection of the object would continue.

e. The ROV would then be controlled to approach the unknown target to record close-up video footage and 35-mm photographs.

f. The ROV would be controlled to ascend to a distance of approximately 1 meter directly above the unknown target and a position fix (integrated subsurface acoustic navigation and surface DGPS) would be taken.

g. If the position for the next unknown target was less than 350 meters distant, the ROV would be controlled to maintain an altitude of approximately 10 meters off the seafloor as the vessel was controlled to slowly transit to the next position. Once at the next unknown target location, the vessel would be controlled to hold station as steps c through f are again performed.

h. If the next unknown target location was more than 350 meters distant, the ROV was to ascend to the surface and be recovered. The next inspection would then start at step a.

These steps would have been repeated until all of the unknown targets had been inspected, or until the time allotted for the Unknown Target ROV Survey/Inspection operations ran out.

### C-6.4 STMC Range Recovery Operations

**C-6.4.1 Range Recovery Detailed Schedule**. Table C-9 gives the detailed schedule for the range recovery operations.

Table C-9. Detailed Range Recovery Schedule

| DATE (1995) | WK. DAY | SHIP LOCATION | RESP. ORG. | OPERATION | COMMENTS |
|---|---|---|---|---|---|
| 08/19 | Sat. | Port Allen/Range | NFESC | Reconfig./Test | Prepare Vessel/Eq. Shakedown |
| 08/20 | Sun. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander |
| 08/21 | Mon. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander |
| 08/22 | Tues. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander |
| 08/23 | Wed. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander |
| 08/24 | Thurs. | STMC Range | NFESC | Target Recovery | Recovery Operations/Divers Arrive |
| 08/25 | Fri. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander&Divers |
| 08/26 | Sat. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander&Divers |
| 08/27 | Sun. | Port Allen | NFESC | Data Input/Off | Data Input/Analysis/A/L |
| 08/28 | Mon. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander&Divers |
| 08/29 | Tues. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander&Divers |
| 08/30 | Wed. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander&Divers |
| 08/31 | Thurs. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander&Divers |
| 09/01 | Fri. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander&Divers |
| 09/02 | Sat. | Port Allen | NFESC | Ship Eq. Repair | Ship Eq. Repair/Umbilical Reterm. |
| 09/03 | Sun. | Port Allen | NFESC | Holiday Day Off | Day Off/A/L |
| 09/04 | Mon. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander&Divers |
| 09/05 | Tues. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander&Divers |
| 09/06 | Wed. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander&Divers |
| 09/07 | Thurs. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander&Divers |
| 09/08 | Fri. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander&Divers |
| 09/09 | Sat. | STMC Range | NFESC | Target Recovery | Recovery Operations/Islander&Divers |
| 09/10 | Sun. | Port Allen | NFESC | Pack Eq.& Hwd | Pack Project Equipment and Targets |
| 09/11 | Mon. | Port Allen | NFESC | Pack/Prep. | Final Packing/Prep. for Transit |
| 09/12 | Tues. | Transit | NFESC | Transit to Oahu | Vessel Transit to Oahu |
| 09/13 | Wed. | Honolulu | NFESC | Demobilization | Demobilization/Pack for Return to CA |
| 09/14 | Thurs. | Honolulu | NFESC | Demobilization | Demobilization/Pack for Return to CA |
| 09/15 | Fri. | Honolulu | NFESC | Final Pack/Move | Final Packing/Secure Aircraft Pallets |

### C-6.4.2 Range Establishment Detailed Procedures.

**C-6.4.2.1 Offshore Target Recovery Operations (M/V American Islander).** The following procedures were performed for target recoveries onto the M/V American Islander:

a. The M/V American Islander was maneuvered to the position of the target to be recovered, and the vessel was controlled to hold station.

b. The ROV and depressor weight were then deployed, and the ROV was controlled to locate the target (as described in the Unknown Target ROV Survey/ Inspection operations section above).

c. The ROV collects position data, a video recording, and a still photograph of the target.

d. The depressor weight is lowered to the seafloor while the ROV operator observes with the vehicle's camera. The operator relays the distance from the seafloor to the depressor weight winch operator. When the depressor weight is resting on the seafloor, the ROV operator informs the winch operator, and an additional 10 meters of slack is deployed from the depressor weight winch. The winch operator notifies the ROV operator that the slack has been deployed.

e. The ROV is then maneuvered to the depressor weight and controlled to grab a recovery line clip with the ROV's three-function manipulator.

f. Once the clip is firmly held in the manipulator, the ROV is controlled to back away from the depressor, and the weight is recovered to a depth of 5 meters off the seafloor.

g. The ROV is then maneuvered back to the target in reverse (to reduce the possibility of line entanglement with the vehicle). The vehicle sonar (360-degree rotation capable), the vehicle aft looking high resolution video camera, and the integrated navigation system display monitor in the ROV van were used to relocate the target. The position fix on the target and the beacon on the vehicle were viewed on integrated navigation system display monitors in the ROV van and on the bridge. The vessel captain held station over the approximate location of the target as the ROV operator guided the vehicle back to the target. Small floats attached to the umbilical between the depressor weight and the vehicle kept the umbilical above of the vehicle (again to reduce the possibility of entanglement).

h. The ROV was controlled to attach the recovery line clip to the target recovery eye and then release the clip.

i. After releasing the clip, the ROV was maneuvered away from the target while still viewing the target with the forward camera.

j. The depressor weight was recovered to the surface as the ROV was controlled to ascend. The ROV was maneuvered to tow the recovery line from the target to the depressor weight (while

maintaining as great a distance as possible from the recovery line and depressor), and then ascended and monitored recovery line payout from the depressor weight stuffing tubes.

k. With the depressor weight at the surface and securely tied to the side of the vessel, a boat hook was used to pull the surface end of the recovery line onto the ship. Using a remote control box from the vessel deck, the ROV operator maintained the ROV a safe distance from the vessel while the targets were recovered.

l. The end of the recovery line was passed around the A-frame structure and tied to a working line from the vessel's deck winch. The working line had already been passed through a sheave attached to the vessel's A-frame.

m. The target was lifted to the ocean surface with the deck winch.

n. The target was then lifted out of the water and onto back deck using the deck winch and the articulating A-frame. Two tag lines were attached to the target for control as the target passed the stern deck of the vessel.

o. The recovery line was slackened, and the target was moved to a storage location with the vessel's crane. The two tag lines were used to control the movement of the target as it was being moved.

p. The ROV was then either recovered and the vessel was maneuvered to the next position, or the depressor weight was deployed to a depth of approximately 20 meters and the ROV was controlled to descend and transit with the vessel while watching the depressor weight.

q. The deck equipment was prepared for the next recovery during the transit.

After three recoveries, the depressor weight and vehicle were recovered. The empty stuffing tubes were then replaced with stuffing tubes filled with recovery lines, and the three clips secured to the ends of the recovery lines were attached to the exterior of the depressor weight. A check-out of the vehicle's condition was performed by two ROV crew members as change-out of the recovery stuffing tubes and clips was being performed.

**C-6.4.2.2 Wash Zone Target Recovery Operations (Divers).** The following procedures were performed to recover the wash zone and beach targets:

a. The project 4-wheel truck was driven to the beach area adjacent to where the target was installed.

b. The portable DGPS was used to locate the target anchor stake on the beach.

c. The anchor stake was pulled out of the sand.

d. The small diameter wire rope was recovered out to the target. Shovels were required.

e. Once at the target, the wire rope was held straight up (pulling against the anchor line) as a position fix was taken.

f. The target was then recovered.

This ended one wash zone target recovery. Steps a through f were repeated for subsequent recoveries.

**C-6.4.2.3 Diver Target Recovery Operations in Water Depths Ranging from 5 to 30 Meters**. The following procedures were performed to recover targets in this area of the STMC range by divers:

a. Using the portable DGPS, the small inflatable boats were maneuvered to the position of the target to be recovered.

b. Divers descended to the target with the end of a recovery line. A hook was attached to the seafloor end of the line. The line was deployed at the surface, from the small inflatable boat, as the divers descended.

c. Divers located the target. The target was typically located visually as the divers were on their way to the seafloor. A circle search of the immediate area was conducted, as required. All of the targets had one or two short floating recovery eyes attached to them. For the targets that were buried, these eyes floated above the surface of the seafloor for target relocation.

d. Divers attached the recovery line to the target recovery eye and communicated to the surface that the attachment was made.

e. Surface personnel then tied a surface float to the line, and notified the divers when the float was in the water.

f. Divers plumbed the surface float and notified the surface. The surface personnel obtained a position fix on the surface float. Surface personnel notified the divers when the fix was obtained, and the divers then slackened the recovery line (slack was needed in the recovery line to bring the float and line to the deck of the LARC-V)

g. Divers collected water depth and target heading data.

h. Divers returned to the surface and were recovered.

i. The LARC-V maneuvered to the position of the target surface float and lifted the float to the deck of the craft with a boat hook.

j. Personnel on the LARC-V recovered the target using the small davit and wire rope winch mounted on the craft.

k. The target was placed in a storage location on the LARC-V and secured for transit.

This concluded one subsea target recovery by divers. As a target was being recovered onto the LARC-V, the divers in the small inflatable boat maneuvered to the next target and began a seafloor search.

## APPENDIX D

## DATABASE FOR CLASSIFICATION AND MAPPING OF UNDERWATER UXO RANGE (DESCRIPTION AND SAMPLE TABLES) INCLUDING AS-INSTALLED PLOTS OF TARGET POSITIONS IN THE RANGE

### D-1 Database Description

The Classification and Mapping of Underwater UXO project database was constructed in Microsoft Access®. The fields available for producing reports are given in Table D-1. Some of these fields do not have data entered at this time for various reasons. For example, MMTC did not report detected target headings or ordnance classes (i.e., practice bomb, 7-inch rocket) for prospects in the demonstration area of the range. Fields can be compared and calculations made with the data in the fields, and the information that is obtained can be placed in tables. For example, Table D-2 contains NFESC assigned target description and classification data, and the MMTC reported target detection data for the calibration area. The "position error" column in Table D-2 was calculated by comparing the NFESC as-installed position data to the MMTC position data collected during the demonstration.

Table D-1. Field Names and Descriptions for the Classification and Mapping of Underwater UXO Database

| FIELD NAME | UNITS | DESCRIPTION |
|---|---|---|
| Target Short Name | | Short descriptive name of each target type (i.e., MK76, ROCK7, CART554, LDRUM, 3SPIPE, etc.) |
| Target Full Name | | Longer, proper name for each target, i.e., MK 76 Practice Bomb, 7" Rocket Warhead, 5" 54 caliber cartridge, large drum, 3" diameter steel pipe, etc. |
| Target Type Class | | Ordnance or non-ordnance |
| Target Ordnance Class | | Ordnance class of each target, i.e., Practice Bomb, Rocket Warhead, Projectile, etc. |
| Target Size Class | | Size class of each target, i.e., large, medium, small (as defined in the report) |
| Target Weight Class | | Weight class of each target, i.e., heavy, medium, light (as defined in the report) |
| Target Length | Inches | Length of the target |
| Target Width or Diameter | Inches | Diameter of the target, or the width of the target if it isn't round or cylindrical |
| Target Height | Inches | Height of the target, this field is left blank on round or cylindrical targets |
| Target Weight | Pounds | Weight of the target |

| | | |
|---|---|---|
| Grouped Target ID | | A numerical ID given to a group of targets if each of the elements within the group have unique serial numbers |
| Element 1 | | Serial number of the first element in the grouped target |
| Element 2 | | Serial number of the second element in the grouped target |
| Element 3 | | Serial number of the third element in the grouped target |
| Element 4 | | Serial number of the fourth element in the grouped target |
| Element 5 | | Serial number of the fifth element in the grouped target |
| Target Counter | | A numerical counter assigned to each of the target cells in the STMC range |
| Image Counter | | A numerical counter assigned to each of the images (still photos and video captures) from the STMC range |
| Image Location | | The location (photocd, computer directory or subdirectory, etc.) where the STMC image may be found |
| File Name | | The file name of digitally stored images |
| File Extension | | The file extension of any digitally stored images |
| File Size | | The size of the digitally stored images |
| Image Comment | | Comments about the digitally stored image |
| Planned Northing | UTM | The planned position (northing) of the target |
| Planned Easting | UTM | The planned position (easting) of the target |
| Planned Water Depth | Meters | The estimated water depth of the planned target position |
| Planned Burial Depth | Meters | If a buried target, the intended burial depth |
| Actual Northing | UTM | The as-installed position (northing) of the target |
| Actual Easting | UTM | The as-installed position (easting) of the target |
| Actual Water Depth | Meters | The water depth of the as-installed target |
| Depth of Burial | Meters | The as-installed burial depth |
| Bottom Type | | The classification of the seafloor at the target location |
| Installation Date | | The date each target was installed |
| Installed By | | An indicator of whether the target was installed by the installation frame or a Navy diver |
| Installation Comments | | Comments and notes recorded during the installation of the target |
| Target Bearing or Target Quad | | The bearing of the target in its as-installed position or the quadrant of the installation frame the target was seen pointing to when resting in its as-installed position |
| Frame Compass Heading | Degrees (Mag.) | The compass heading of the installation frame when the target quadrant was determined |
| Target Azimuth - Minimum | Degrees | The minimum possible target bearing based on the target quadrant and the frame heading |
| Target Azimuth - Maximum | Degrees | The maximum possible target bearing based on the target quadrant and the frame heading |
| Anchored Target | | An indicator of whether the target was anchored to the seafloor or not |

| | | |
|---|---|---|
| Tethered Target | | An indicator of whether the target was tethered to shore or not |
| Faired Target | | An indicator of whether the target was stabilized with a plastic fairing or not |
| Recovery Date | | The date each target was recovered |
| Recovered By | | An indicator of whether the target was recovered by the ROV or a Navy diver |
| Target Verification | | An indicator of whether the target serial number was verified when the target was recovered |
| Recovered Northing | UTM | The as-recovered position (northing) of the target |
| Recovered Easting | UTM | The as-recovered position (easting ) of the target |
| Recovery Comments | | Comments on the target recovery |
| Site Name | | The name of each target cell, i.e., C001 - C056 and D001 - D193 ("C" for Calibration range, "D" for Demonstration range) |
| Demonstration Team Identifier | | A short name that identifies the demonstration group. Included with this name is the year that the demonstration took place. For example MMTC95 |
| Demonstration Dates | M/D-M/D Year | Start and finish dates for the demonstration |
| Demonstration Target Northing | UTM | The position (northing) reported for the targets detected during the demonstration |
| Demonstration Target Easting | UTM | The position (easting) reported for the targets detected during the demonstration |
| Demonstration Target Type Class (ord./non-ord.) | | Class of each detected target regarding ordnance or non-ordnance |
| Demonstration Target Ordnance Class (target type) | | Class of each detected target type, i.e., Practice Bomb, Rocket Warhead, Projectile, etc. |
| Demonstration Target Weight Class (weight) | | Class of each detected target by weight, i.e., heavy, medium, light (as defined in report) |
| Demonstration Target Size Class (size) | | Class of each detected target by size, i.e., large, medium, small (as defined in report) |
| Demonstration Target Water Depth | Meters | The water depth of each detected target |
| Demonstration Target Burial Depth | Meters | The burial depth of each detected target (0 for surface laying) |
| Demonstration Target Grouping | | Indication of detected target grouping. If yes, the number in the group is supplied |
| Demonstration Target Heading | Degrees (Mag.) | The detected target heading |
| Video Counter | | A numerical counter assigned to each of the available segments of video footage |
| Tape Source | | The source of the video footage, i.e., either installation frame, diver, or ROV |
| Tape Number | | The video tape number |
| Start Time | Hr.:Min.: Sec. | The start time of a particular video tape segment |
| Stop Time | Hr.:Min.: Sec. | The stop time of a particular video tape segment |
| Video Comment | | Comments on a video tape segment |
| Source of Target | | The source of inert ordnance targets |
| Target Serial Number | | The unique number assigned to and etched onto each target |
| Present Location | | The present location of a target, i.e., in use at a particular range, lost at a particular range, in storage at NFESC, etc. |

| | | |
|---|---|---|
| Labels | | General and specific labels on each target |
| Markings | | General and specific markings on each target |
| Source of Target | | An abbreviation for the actual name of the organization that supplied the target |
| Date Obtained | | The date a particular target was obtained |
| Obtained from POC | | The POC a particular target was obtained from |
| Target Source Organization | | Full name of the organization that supplied the target |
| Organization | | Name of organization associated with the planning or implementation of the test range. |
| Title | | The title of the person at a particular organization, i.e., Dr., Mrs., LCDR, etc. |
| Name | | The person's name, last name first |
| Position | | The person's position within their organization, i.e., Program Manager, Civil Engineer, Supply Officer, etc. |
| Domain | | The person's domain within their organization, i.e., Code ESC52, University of Hawaii Vessels, Demonstration Systems, etc. |
| Phone Number | | The person's phone number (commercial and DSN, if available) and extension |
| Fax Number | | The person's fax number |
| E-mail Address | | The person's e-mail address |
| Address | | The person's mailing address |

## D-2 Calibration Area Target Actual and Detected Data

Table D-2 contains actual and detected data for targets in the calibration area. Multiple entries of the same site name are made in this table. These sites were passed over by the side-scan sonar more than once. A total of 26 individual targets were detected by the demonstrators in this area of the range.

Table D-2. Calibration Area Target Actual and Detected Data

| SITE NAME (NFESC) | ASSIGNED DESCRIPTION (NFESC) | ASSIGNED CLASSIFICATION (NFESC) | DEMONSTRATION CLASSIFICATION (MMTC Class 1, 2, 3) | PROSPECT DESCRIPTION (MMTC) | POSITION ERROR (meters) |
|---|---|---|---|---|---|
| C006 | MK81 Large Bomb | Large, Heavy | Large, Heavy (1) | small, bright | 16 |
| C007 | MK81 Large Bomb | Large, Heavy | Large, Heavy (1) | small, medium | 11 |
| C008 | FRAG Large Bomb | Large, Heavy | Large, Heavy (1) | large, medium | 52 |
| C008 | FRAG Large Bomb | Large, Heavy | Large, Heavy (1) | small, medium repeated | 82 |
| C009 | MK82 Large Bomb | Large, Heavy | Large, Heavy (1) | large, bright | 23 |
| C009 | MK82 Large Bomb | Large, Heavy | Large, Heavy (1) | medium, bright | 23 |
| C010 | MK81 Large Bomb | Large, Heavy | Large, Heavy (1) | small, medium | 27 |
| C019 | 3MK106 Practice Bomb | Medium, Light | Medium, Light (3) | very small, medium | 24 |
| C020 | MK76 Practice Bomb | Medium, Medium | Medium, Medium (2) | small, bright | 49 |

| | | | | | |
|---|---|---|---|---|---|
| C020 | MK76 Practice Bomb | Medium, Medium | Medium, Medium (2) | small, medium doublet | 49 |
| C020 | MK76 Practice Bomb | Medium, Medium | Medium, Medium (2) | nothing, | 20 |
| C021 | MK76 Practice Bomb | Medium, Medium | Medium, Medium (2) | medium, bright repeated | 43 |
| C021 | MK76 Practice Bomb | Medium, Medium | Medium, Medium (2) | medium, medium | 10 |
| C021 | MK76 Practice Bomb | Medium, Medium | Medium, Medium (2) | small, medium | 33 |
| C021 | MK76 Practice Bomb | Medium, Medium | Medium, Medium (2) | medium, bright | 36 |
| C023 | MK76 Practice Bomb | Medium, Medium | Medium, Medium (2) | medium, bright repeated | 82 |
| C023 | MK76 Practice Bomb | Medium, Medium | Medium, Medium (2) | medium, bright | 50 |
| C023 | MK76 Practice Bomb | Medium, Medium | Medium, Medium (2) | medium, bright | 50 |
| C031 | ROCK5 Rocket Warhead | Medium, Medium | Medium, Medium (2) | medium, bright | 35 |
| C031 | ROCK5 Rocket Warhead | Medium, Medium | Medium, Medium (2) | small thin, medium | 3 |
| C031 | ROCK5 Rocket Warhead | Medium, Medium | Medium, Medium (2) | medium, bright | 35 |
| C032 | PROJ538 Projectile | Medium, Medium | Medium, Medium (2) | small, medium doublet | 57 |
| C032 | PROJ538 Projectile | Medium, Medium | Medium, Medium (2) | small, bright | 57 |
| C032 | PROJ538 Projectile | Medium, Medium | Medium, Medium (2) | medium, medium | 48 |
| C033 | PROJ538 Projectile | Medium, Medium | Medium, Medium (2) | medium, bright | 27 |
| C033 | PROJ538 Projectile | Medium, Medium | Medium, Medium (2) | medium, bright | 26 |
| C035 | PROJ554 Projectile | Medium, Medium | Medium, Medium (2) | small thin, bright | 59 |
| C035 | PROJ554 Projectile | Medium, Medium | Medium, Medium (2) | medium, bright repeated | 54 |
| C041 | ROCK5 Rocket Warhead | Medium, Medium | Medium, Medium (2) | small, medium | 19 |
| **C042 *** | ROCK7 Rocket Warhead | Large, Medium-buried | Medium, Medium(2)-buried | small thin, medium | 38 |
| C043 | ROCK5 Rocket Warhead | Medium, Medium | Medium, Medium (2) | small, bright | 52 |
| C043 | ROCK5 Rocket Warhead | Medium, Medium | Medium, Medium (2) | small, medium | 51 |
| C043 | ROCK5 Rocket Warhead | Medium, Medium | Medium, Medium (2) | small, bright | 50 |
| C045 | ROCK5 Rocket Warhead | Medium, Medium | Medium, Medium (2) | nothing | 44 |
| C047 | ROCK7 Rocket Warhead | Large, Medium | Medium, Medium (2) | small thin, bright | 69 |
| C049 | ROCK275 Rocket Warhead | Small, Light | Small,Light (3) | small, bright | 26 |
| C049 | ROCK275 Rocket Warhead | Small, Light | Small,Light (3) | small, bright | 26 |
| C050 | CART20M Other | Small, Light | Small,Light (3) | very small, medium | 5 |
| C051 | CART554 Other | Medium, Medium | Medium, Medium (2) | very small, medium | 8 |
| C052 | CASE40M Other | Small, Light | Small,Light (3) | very small, medium | 27 |
| C053 | MK106 Practice Bomb | Medium, Light | Medium, Light (3) | nothing | 12 |
| **C054 *** | Cable #N/a | Small, Medium - buried | Large, Medium (2-3)-buried | large, medium | 13 |
| C055 | ROCK7 Rocket Warhead | Large, Medium | Medium, Medium (2) | nothing | 8 |
| C056 | 2ROCK275Rocket Warhead | Small, Light | Small,Light (3) | very small, medium | 30 |

* Indicated buried target/prospect

## D-3 Classification and Mapping of Underwater UXO FY95 Target Installation Data

Table D-3 contains selected data for each of the targets installed in the range.

Table D-3. Selected Target Data for the Calibration and Demonstration Areas of the Range (all targets)

| SITE NAME | TARGET SHORT NAME | SIZE CLASS | WEIGHT CLASS | NORTHING (meters) | EASTING (meters) | WATER DEPTH (meters) | BURIAL DEPTH (meters) | SEAFLOOR TYPE AT SITE |
|---|---|---|---|---|---|---|---|---|
| CALIBRATION AREA | | | | | | | | |
| C001 | ROCK275 | Small | Light | 2430625.5 | 421898.7 | 0 | | Sand Ripples |
| C002 | MK106 | Medium | Light | 2430470.15 | 421818.85 | 4.6 | | Sand Ripples |
| C003 | FRAG | Large | Heavy | 2430377.6 | 421769.05 | 8.2 | | Sand Ripples |
| C004 | FRAG | Large | Heavy | 2430298.9 | 421707.15 | 12 | | Sand Ripples |
| C005 | MK81 | Large | Heavy | 2430207.09 | 421656.8 | 17.4 | | Smooth Sand |
| C006 | MK81 | Large | Heavy | 2430126.34 | 421608.04 | 20.7 | | Rubble & Sand with Algae |
| C007 | MK81 | Large | Heavy | 2430028.8 | 421560.41 | 27.4 | | Sand Ripples |
| C008 | FRAG | Large | Heavy | 2429945.5 | 421504.41 | 32.3 | | Sand Ripples |
| C009 | MK82 | Large | Heavy | 2429866.63 | 421448.61 | 35.4 | | Smooth Sand |
| C010 | MK81 | Large | Heavy | 2429783.29 | 421401.21 | 39.3 | | Smooth Sand |
| C011 | MK81 | Large | Heavy | 2429686.5 | 421350.83 | 45.7 | | Smooth Sand |
| C012 | FRAG | Large | Heavy | 2429605.71 | 421308.61 | 53.6 | | Smooth Sand |
| C013 | MK76 | Medium | Medium | 2430640.6 | 421799.2 | 0.9 | | Smooth Sand |
| C014 | MK106 | Medium | Light | 2430514.6 | 421726.6 | 4.6 | | Smooth Sand |
| C015 | MK76 | Medium | Medium | 2430437.4 | 421674.23 | 8.2 | | Smooth Sand |
| C016 | 3MK106 | Medium | Light | 2430347.62 | 421630.99 | 12 | | Smooth Sand |
| C017 | MK106 | Medium | Light | 2430260.46 | 421572.05 | 18.4 | | Smooth Sand |
| C018 | MK76 | Medium | Medium | 2430173.81 | 421522.06 | 21.2 | 0.2 | Rubble & Sand |
| C019 | 3MK106 | Medium | Light | 2430082.72 | 421476.01 | 29.4 | | Rubble & Sand |
| C020 | MK76 | Medium | Medium | 2430003.7 | 421411.95 | 32.5 | | Sand Ripples |
| C021 | MK76 | Medium | Medium | 2429932.13 | 421373.91 | 35.9 | | Sand Ripples |
| C022 | MK106 | Medium | Light | 2429832.59 | 421318.17 | 39.8 | 0.1 | Sand Ripples |
| C023 | MK76 | Medium | Medium | 2429746.13 | 421268.01 | 45.1 | | Smooth Sand |
| C024 | MK76 | Medium | Medium | 2429657.98 | 421224.37 | 55.4 | | Smooth Sand |
| C025 | PROJ554 | Medium | Medium | 2430678.9 | 421720.7 | 0.9 | | Smooth Sand |
| C026 | PROJ538 | Medium | Medium | 2430592.2 | 421629.35 | 4.3 | | Smooth Sand |
| C027 | PROJ538 | Medium | Medium | 2430485.27 | 421589.49 | 8.8 | | Smooth Sand |
| C028 | PROJ554 | Medium | Medium | 2430405.99 | 421541.46 | 12.8 | | Sand Waves |
| C029 | PROJ554 | Medium | Medium | 2430307.18 | 421488.65 | 17 | | Smooth Sand |
| C030 | PROJ538 | Medium | Medium | 2430231.8 | 421436.83 | 24.7 | 0.1 | Rubble & Sand |
| C031 | ROCK5 | Medium | Medium | 2430143.84 | 421390.1 | 31.3 | | Sand Ripples |
| C032 | PROJ538 | Medium | Medium | 2430054.08 | 421335.97 | 33.5 | | Sand Ripples |
| C033 | PROJ538 | Medium | Medium | 2429968.38 | 421280.64 | 36.3 | | Sand Waves |
| C034 | PROJ538 | Medium | Medium | 2429885.42 | 421232.22 | 39.8 | | Smooth Sand |
| C035 | PROJ554 | Medium | Medium | 2429799.7 | 421179.65 | 45.2 | | Smooth Sand |
| C036 | PROJ554 | Medium | Medium | 2429706.25 | 421125.84 | 56.7 | | Smooth Sand |
| C037 | ROCK275 | Small | Light | 2430760.8 | 421658.4 | 0 | | Sand Ripples |
| C038 | ROCK5 | Medium | Medium | 2430651.55 | 421599.65 | 3.7 | | Sand Ripples |
| C039 | ROCK7 | Large | Medium | 2430545.85 | 421492.54 | 8.2 | | Sand Ripples |
| C041 | ROCK5 | Medium | Medium | 2430359.46 | 421400.81 | 18.6 | | Sand Ripples |
| C042 | ROCK7 | Large | Medium | 2430275.58 | 421351.01 | 26.6 | 0.3 | Sand Ripples |
| C043 | ROCK5 | Medium | Medium | 2430197.41 | 421301.92 | 32.3 | | Sand Ripples |
| C044 | ROCK275 | Small | Light | 2430105.8 | 421249.32 | 34.5 | | Sand Ripples |
| C045 | ROCK5 | Medium | Medium | 2430017.83 | 421205.35 | 37.5 | | Sand Ripples |
| C046 | ROCK7 | Large | Medium | 2429930.86 | 421146.75 | 40.5 | | Smooth Sand |
| C047 | ROCK7 | Large | Medium | 2429854.9 | 421099.22 | 46.9 | | Smooth Sand |
| C048 | ROCK5 | Medium | Medium | 2429766.62 | 421043.88 | 57 | | Smooth Sand |
| C049 | ROCK275 | Small | Light | 2430368.86 | 421329.44 | 23.8 | | Sand Ripples |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| C050 | CART20M | Small | Light | 2430301.5 | 421258.04 | 29.9 | | Sand Ripples |
| C051 | CART554 | Medium | Medium | 2430437.14 | 421251.83 | 22.3 | | Sand Ripples |
| C052 | CASE40M | Small | Light | 2430357.04 | 421182.77 | 28.5 | | Sand Ripples |
| C053 | MK106 | Medium | Light | 2430503.92 | 421178.17 | 21.4 | | Sand Ripples |
| C054 | CABLE | Small | Medium | 2430425.83 | 421113.25 | 28.1 | 0.2 | Smooth Sand |
| C055 | ROCK7 | Large | Medium | 2430566.4 | 421101.85 | 20.5 | | Sand Ripples |
| C056 | 2ROCK275 | Small | Light | 2430496.89 | 421033.94 | 27.6 | | Sand Ripples |
| **DEMONSTRATION AREA** | | | | | | | | |
| D001 | CART20M | Small | Light | 2429958.11 | 421028.8 | 44.1 | | Smooth Sand |
| D002 | FRAG | Large | Heavy | 2429983.49 | 420946.32 | 45.4 | | Rubble & Sand with Algae |
| D003 | PROJ554 | Medium | Medium | 2430043.08 | 420841.52 | 47.1 | | Rubble & Sand with Algae |
| D004 | LDRUM | Large | Heavy | 2430059.26 | 421030.44 | 39.4 | | Smooth Sand |
| D005 | PROJ554 | Medium | Medium | 2430075.96 | 421127.85 | 37.6 | | Sand Ripples |
| D006 | MDRUM | Large | Medium | 2430104.31 | 420914.68 | 41.4 | | Smooth Sand |
| D007 | MK76 | Medium | Medium | 2430119.42 | 420615.81 | 53.8 | | Smooth Sand |
| D008 | AM_BOX | Large | Medium | 2430157.9 | 420753.81 | 44.3 | | Smooth Sand |
| D009 | CHAIN | Medium | Medium | 2430169.8 | 420986.73 | 38.7 | | Sand Ripples |
| D010 | AM_BOX | Large | Medium | 2430171.01 | 421087.32 | 36.1 | | Sand Ripples |
| D011 | PROJ554 | Medium | Medium | 2430195.25 | 420379.87 | 55.3 | | Smooth Sand |
| D012 | 8SPIPE | Large | Heavy | 2430207.6 | 420482.86 | 53.2 | | Smooth Sand |
| D013 | MK76 | Medium | Medium | 2430218.79 | 421236.82 | 32.2 | | Smooth Sand |
| D014 | PROJ554 | Medium | Medium | 2430254.69 | 420841.89 | 37.7 | | Sand Waves |
| D015 | MK76 | Medium | Medium | 2430267.29 | 420614.71 | 45.5 | | Sand Ripples |
| D016 | 3MK106 | Medium | Light | 2430280.27 | 421113.73 | 33 | | Sand Ripples |
| D017 | MK76 | Medium | Medium | 2430271.73 | 420241.24 | 56 | | Smooth Sand |
| D018 | 22LINK | Medium | Medium | 2430303.61 | 420387.71 | 49.5 | | Smooth Sand |
| D019 | ROCK5 | Medium | Medium | 2430300.31 | 420979.95 | 35.1 | | Sand Ripples |
| D020 | 5APIPE | Medium | Light | 2430344.46 | 420746.66 | 37.8 | | Sand Ripples |
| D021 | ROCK5 | Medium | Medium | 2430352.21 | 420568.04 | 43.8 | | Sand Ripples |
| D022 | 3SPIPE | Small | Light | 2430358.35 | 420846.37 | 35.4 | | Sand Ripples |
| D023 | MK106 | Medium | Light | 2430373.33 | 420331.03 | 48.9 | | Sand Ripples |
| D024 | CASE40M | Small | Light | 2430377.2 | 420216.82 | 51.9 | | Smooth Sand |
| D025 | CART20M | Small | Light | 2430412 | 420489.17 | 43.2 | | Sand Ripples |
| D026 | AM_BOX | Large | Medium | 2430435.4 | 420712.05 | 36.6 | | Sand Ripples |
| D027 | ROCK5 | Medium | Medium | 2430440.15 | 420599.12 | 39.7 | | Sand Ripples |
| D028 | MK106 | Medium | Light | 2430458.34 | 420811.88 | 34.4 | | Sand Ripples |
| D029 | ROCK5 | Medium | Medium | 2430471.91 | 420949.41 | 30.9 | | Sand Ripples |
| D030 | PROJ538 | Medium | Medium | 2430497.09 | 421401.67 | 12.7 | 0.3 | Sand Ripples |
| D031 | MK106 | Medium | Light | 2430499.12 | 420092.06 | 52.2 | | Smooth Sand |
| D032 | 4SPIPEL | Medium | Medium | 2430530.06 | 420492.59 | 39.9 | | Smooth Sand |
| D033 | MK76 | Medium | Medium | 2430578.61 | 420258.25 | 42.6 | | Smooth Sand |
| D034 | ROCK275 | Small | Light | 2430601.03 | 420815.08 | 28.5 | | Sand Ripples |
| D035 | ROCK7 | Large | Medium | 2430597.43 | 420410.33 | 38.8 | | Sand Ripples |
| D036 | MK81 | Large | Heavy | 2430608.46 | 420571.17 | 32.9 | | Smooth Sand |
| D037 | MK76 | Medium | Medium | 2430613.33 | 421325.5 | 10.3 | 0.2 | Sand Waves |
| D038 | MK82 | Large | Heavy | 2430646.85 | 420333.77 | 39.3 | | Smooth Sand |
| D039 | MK106 | Medium | Light | 2430656.32 | 420948.73 | 21.6 | | Sand Ripples |
| D040 | PROJ554 | Medium | Medium | 2430671.65 | 421209.98 | 12.1 | 0.1 | Sand Ripples |
| D041 | 4SPIPE | Medium | Medium | 2430735.75 | 421478.3 | 3.6 | | Sand Ripples |
| D042 | ROCK5 | Medium | Medium | 2430677.75 | 421097.47 | 16.5 | 0.1 | Sand Ripples |
| D043 | CART554 | Medium | Medium | 2430694.22 | 420636.61 | 27.8 | | Rubble & Sand |
| D044 | ROCK275 | Small | Light | 2430696.96 | 420084.37 | 44.1 | | Sand Ripples |
| D045 | ROCK7 | Large | Medium | 2430706.85 | 420259.31 | 36.7 | | Rubble & Sand |
| D046 | 2MK76 | Medium | Medium | 2430720.6 | 420759.28 | 25.9 | | Sand Ripples |
| D047 | 2PROJ538 | Medium | Medium | 2430751.5 | 420432.89 | 30.3 | | Rubble & Sand |
| D048 | MK106 | Medium | Light | 2430754.47 | 420522.62 | 27.9 | | Rubble & Sand |
| D049 | PROJ554 | Medium | Medium | 2430860.8 | 421477.9 | 0.9 | | Sand Waves |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| D050 | ROCK7 | Large | Medium | 2430776.45 | 421208.96 | 8.7 | | Sand Waves |
| D051 | CLINK | Large | Medium | 2430801.14 | 420001.21 | 46 | | Sand Waves |
| D052 | MK106 | Medium | Light | 2430797.89 | 420190.33 | 36.9 | | Rubble & Sand with Algae |
| D053 | MK106 | Medium | Light | 2430848.35 | 421389.95 | 3.1 | | Sand Waves |
| D054 | 2PROJ538 | Medium | Medium | 2430837.67 | 420508.39 | 26.7 | | Rubble & Sand |
| D055 | PROJ554 | Medium | Medium | 2430868.15 | 421260.95 | 6.1 | | Sand Waves |
| D056 | CART554 | Medium | Medium | 2430865.6 | 420793.67 | 20.5 | | Sand Ripples |
| D057 | ROCK5 | Medium | Medium | 2430903.78 | 420355.19 | 27.4 | | Rubble & Sand |
| D058 | ROCK7 | Large | Medium | 2430797.89 | 420190.33 | 36.9 | | Rubble & Sand |
| D059 | CART20M | Small | Light | 2430934.18 | 420658.25 | 21.4 | | Sand Ripples |
| D060 | MK76 | Medium | Medium | 2430954.89 | 420463.74 | 26.3 | | Sand Waves |
| D061 | LDRUM | Large | Heavy | 2430962.8 | 420125.88 | 32.6 | | Rubble & Sand |
| D062 | IBEAM | Medium | Medium | 2430975.53 | 419884.11 | 41.7 | | Rubble & Sand |
| D063 | PROJ538 | Medium | Medium | 2430985.68 | 421033.39 | 9.6 | 0.3 | Sand Ripples |
| D064 | ROCK275 | Small | Light | 2431035 | 421230.6 | 2.3 | | Sand Ripples |
| D065 | ROCK275 | Small | Light | 2431024.95 | 420891.27 | 12.7 | | Sand Ripples |
| D066 | PROJ554 | Medium | Medium | 2431051.07 | 420746.6 | 17.8 | | Sand Ripples |
| D067 | MDRUM | Large | Medium | 2431052.84 | 420277.59 | 26.7 | | Rubble & Sand |
| D068 | PROJ554 | Medium | Medium | 2431064.01 | 420039.66 | 33 | | Rubble & Sand |
| D069 | ROCK7 | Large | Medium | 2431071.84 | 420153.64 | 27.7 | | Rubble & Sand |
| D070 | MK76 | Medium | Medium | 2431075.6 | 421186.45 | 3.3 | | Smooth Sand |
| D071 | MDRUM | Large | Medium | 2431093.01 | 420513.99 | 21.9 | | Rubble & Sand |
| D072 | ROCK7 | Large | Medium | 2431110.4 | 420979.79 | 8.6 | | Smooth Sand |
| D073 | CART554 | Medium | Medium | 2431116.66 | 420616.49 | 20.5 | | Sand Ripples |
| D074 | PROJ538 | Medium | Medium | 2431122.23 | 419843.06 | 38 | | Rubble & Sand |
| D075 | CART20M | Small | Light | 2431128.39 | 420795.44 | 12.7 | | Sand Ripples |
| D076 | BBEAM | Medium | Medium | 2431144.51 | 419965.92 | 32.6 | | Smooth Sand |
| D077 | MK76 | Medium | Medium | 2431145.8 | 421236.6 | 0.9 | | Smooth Sand |
| D078 | 4SPIPE | Medium | Medium | 2431194.35 | 421121.25 | 1.9 | | Smooth Sand |
| D079 | CART554 | Medium | Medium | 2431186.45 | 420387.47 | 21.2 | | Rubble & Sand, Coral |
| D080 | PROJ554 | Medium | Medium | 2431216.19 | 420231.77 | 25.2 | | Sand Ripples |
| D081 | ROCK5 | Medium | Medium | 2431214.42 | 420474.34 | 21.5 | | Sand Waves |
| D082 | 2PROJ538 | Medium | Medium | 2431219.63 | 420828.46 | 10.8 | | Sand Ripples |
| D083 | AM_BOX | Large | Medium | 2431222.02 | 420673.03 | 16.5 | | Sand Ripples |
| D084 | 3ROCK275 | Small | Light | 2431227.5 | 419918.8 | 30.9 | | Rubble & Sand |
| D085 | ROCK7 | Large | Medium | 2431234.37 | 420945.66 | 7.6 | | Sand Ripples |
| D086 | CASE40M | Small | Light | 2431234.52 | 420010.83 | 27.7 | | Smooth Sand |
| D087 | ROCK7 | Large | Medium | 2431280.1 | 421158.3 | 0.9 | | Sand Ripples |
| D088 | ROCK275 | Small | Light | 2431256.77 | 420148.94 | 25.5 | | Smooth Sand |
| D089 | PROJ554 | Medium | Medium | 2431301.29 | 419641.96 | 40.6 | | Rubble & Sand |
| D090 | FRAG | Large | Heavy | 2431313.26 | 419867.16 | 30.2 | | Rubble & Sand with Algae |
| D091 | FRAG | Large | Heavy | 2431316.34 | 420569.31 | 17.8 | 0.6 | Sand Ripples |
| D092 | CART762 | Small | Light | 2431322.73 | 420377.23 | 20.5 | | Rubble & Sand |
| D093 | GRATE | Large | Medium | 2431356.3 | 420218.34 | 20.7 | | Rubble & Sand with Algae |
| D094 | AM_BOX | Large | Medium | 2431370.45 | 420860.45 | 7.6 | | Smooth Sand |
| D095 | PROJ554 | Medium | Medium | 2431363.2 | 421009.3 | 2.8 | | Smooth Sand |
| D096 | 5APIPE | Medium | Light | 2431390.51 | 419547.43 | 41.4 | | Smooth Sand |
| D097 | 3SPIPE | Small | Light | 2431416.13 | 420354.04 | 19.7 | | Sand Ripples |
| D098 | ROCK275 | Small | Light | 2431427.74 | 420611.52 | 14.4 | | Sand Ripples |
| D099 | AM_BOX | Large | Medium | 2431458.4 | 420971.95 | 1.6 | | Smooth Sand |
| D100 | ROCK275 | Small | Light | 2431453.58 | 420719.32 | 10.7 | | Sand Ripples |
| D101 | CART554 | Medium | Medium | 2431458.43 | 419615.05 | 36.7 | | Rubble & Sand |
| D102 | PROJ538 | Medium | Medium | 2431447.02 | 420870.3 | 6.1 | | Smooth Sand |
| D103 | MK83 | Large | Heavy | 2431469.38 | 419965.61 | 25.6 | | Smooth Sand |
| D104 | CART20M | Small | Light | 2431491.21 | 420465.23 | 17.6 | | Sand Ripples |
| D105 | LCHAIN | Medium | Medium | 2431495.27 | 419843.92 | 27.5 | | Rubble & Sand |
| D106 | CART554 | Medium | Medium | 2431506.26 | 420224.59 | 20.1 | | Rubble & Sand |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| D107 | MK106 | Medium | Light | 2431530.09 | 419745.67 | 27.9 | | Rubble & Sand with Algae |
| D108 | 12SPIPE | Large | Heavy | 2431551.28 | 420040.19 | 21.6 | | Rubble & Sand |
| D109 | ROCK7 | Large | Medium | 2431557.24 | 420138.47 | 20.3 | | Rubble & Sand |
| D110 | MK76 | Medium | Medium | 2431579.45 | 420793.1 | 6.7 | | Smooth Sand |
| D111 | CART554 | Medium | Medium | 2431585.41 | 419355.4 | 42.4 | | Smooth Sand |
| D112 | 8SPIPE | Large | Heavy | 2431609.96 | 420367.58 | 17.8 | | Sand Ripples |
| D113 | LCHAIN | Medium | Medium | 2431629.41 | 420279.93 | 18.8 | 0.1 | Sand Ripples |
| D114 | FRAG | Large | Heavy | 2431628.17 | 419982.05 | 21.2 | | Rubble & Sand |
| D115 | FRAG | Large | Heavy | 2431645.4 | 420473.06 | 15.2 | | Sand Ripples |
| D116 | MK106 | Medium | Light | 2431642.95 | 420662.75 | 9.5 | 0.2 | Sand Ripples |
| D117 | MK106 | Medium | Light | 2431648.38 | 419878.43 | 23.5 | | Sand Ripples |
| D118 | SDRUM | Large | Light | 2431663.39 | 419781.38 | 24.8 | | Smooth Sand |
| D119 | ROCK275 | Small | Light | 2431671.41 | 419307.51 | 43.4 | | Smooth Sand |
| D120 | PROJ554 | Medium | Medium | 2431703.45 | 420850.35 | 2.9 | | Smooth Sand |
| D121 | PROJ554 | Medium | Medium | 2431753.8 | 420590.05 | 11 | | Smooth Sand |
| D122 | 2MK76 | Medium | Medium | 2431749.5 | 419999.81 | 19.9 | | Rubble & Sand |
| D123 | MK76 | Medium | Medium | 2431839.1 | 420795.5 | 2.4 | | Sand Ripples |
| D124 | MK76 | Medium | Medium | 2431795.65 | 420686.75 | 6.4 | | Sand Ripples |
| D125 | 4SPIPE | Medium | Medium | 2431823.26 | 419336.16 | 37.3 | | Rock Outcrop Flat |
| D126 | MK76 | Medium | Medium | 2431833.27 | 419204.43 | 44.1 | | Smooth Sand |
| D127 | 3MK106 | Medium | Light | 2431839.33 | 419659.42 | 23.9 | | Rubble & Sand |
| D128 | 3MK106 | Medium | Light | 2431838.98 | 420333.47 | 17.2 | | Rubble & Sand |
| D129 | PROJ554 | Medium | Medium | 2431849.92 | 419943.3 | 19.4 | 0.1 | Rubble & Sand |
| D130 | CASE40M | Small | Light | 2431899.7 | 420091.87 | 16 | | Rubble & Sand with Algae |
| D131 | CASE40M | Small | Light | 2431908.3 | 419857.29 | 19.9 | | Rubble & Sand |
| D132 | PROJ538 | Medium | Medium | 2431913.05 | 420578.55 | 9.1 | | Smooth Sand |
| D133 | 2MK76 | Medium | Medium | 2431928.52 | 419176.48 | 43.9 | | Rubble & Sand with Algae |
| D134 | ROCK7 | Large | Medium | 2431933.13 | 419409.38 | 25.3 | | Rubble & Sand |
| D135 | MK106 | Medium | Light | 2431940.13 | 419771.54 | 21.2 | | Rubble & Sand with Algae |
| D136 | PROJ538 | Medium | Medium | 2431951.1 | 420744 | 2.8 | | Smooth Sand |
| D137 | 2ROCK5 | Medium | Medium | 2431950.11 | 420226.47 | 17.3 | | Cave |
| D138 | ROCK5 | Medium | Medium | 2431971.1 | 419081.68 | 45.1 | | Rubble & Sand with Algae |
| D139 | 4SPIPE | Medium | Medium | 2431976.13 | 420364.83 | 15.1 | | Sand Ripples |
| D140 | PROJ538 | Medium | Medium | 2432026.67 | 419907.41 | 18.7 | | Rock Outcrop Shaped |
| D141 | MK82 | Large | Heavy | 2432025.81 | 419598.82 | 24.7 | | Rock Outcrop Flat |
| D142 | MK106 | Medium | Light | 2432026.2 | 420540.3 | 8.5 | | Smooth Sand |
| D143 | ROCK275 | Small | Light | 2432041.94 | 419709.13 | 19.5 | | Rubble & Sand with Algae |
| D144 | 3SPIPE | Small | Light | 2432039.13 | 420040.76 | 16.3 | | Rubble & Sand with Algae |
| D145 | CASE40M | Small | Light | 2432076.56 | 419297.86 | 32.2 | | Rubble & Sand with Algae |
| D146 | ROCK7 | Large | Medium | 2432080.07 | 418967.85 | 46.9 | | Smooth Sand |
| D147 | MK76 | Medium | Medium | 2432090.84 | 420407.11 | 12.5 | 0.3 | Sand Ripples |
| D148 | ROCK7 | Large | Medium | 2432099.19 | 419854.45 | 17.5 | | Rock Outcrop Shaped |
| D149 | 3MK106 | Medium | Light | 2432106.36 | 419198.2 | 40.4 | | Rubble & Sand |
| D150 | 3ROCK275 | Small | Light | 2432137.43 | 419087.61 | 42.2 | | Rubble & Sand with Algae |
| D151 | MK106 | Medium | Light | 2432141.1 | 420533.1 | 6.7 | | Sand Ripples |
| D152 | MK76 | Medium | Medium | 2432167.82 | 419435.73 | 23.7 | | Rubble & Sand with Algae |
| D153 | 5APIPE | Medium | Light | 2432173.9 | 420638.8 | 3.1 | | Sand Ripples |
| D154 | ROCK7 | Large | Medium | 2432189.7 | 419012.77 | 44.1 | | Rubble & Sand |
| D155 | MK106 | Medium | Light | 2432185.12 | 419303.24 | 25.5 | | Rubble & Sand with Algae |
| D156 | ROCK7 | Large | Medium | 2432202.37 | 419762.59 | 17.9 | | Sand Ripples |
| D157 | ROCK275 | Small | Light | 2432207.01 | 420313.81 | 12.3 | | Rock Outcrop Shaped |
| D158 | MK81 | Large | Heavy | 2432225.74 | 418830.21 | 47.5 | | Smooth Sand |
| D159 | MK76 | Medium | Medium | 2432268.45 | 420586.7 | 3.7 | | Sand Ripples |
| D160 | MK81 | Large | Heavy | 2432260.33 | 419459.57 | 23 | | Sand Ripples, Rock Outcrop |
| D161 | MK76 | Medium | Medium | 2431644.2 | 420955.4 | 0.9 | | Sand Ripples |
| D162 | PROJ554 | Medium | Medium | 2432260.8 | 420420.5 | 9.8 | | Sand Ripples |
| D163 | MK76 | Medium | Medium | 2432272.06 | 419878.35 | 14.5 | | Rubble & Sand with Algae |

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|---|---|---|---|---|---|---|---|---|
| D164 | 4SPIPE | Medium | Medium | 2432290.51 | 418741.19 | 47.7 | | Rubble & Sand with Algae |
| D165 | PROJ554 | Medium | Medium | 2432291.92 | 419371.6 | 24.8 | | Rubble & Sand with Algae |
| D166 | 2MK76 | Medium | Medium | 2432311.37 | 419706.69 | 15.2 | | Rubble & Sand w/Algae, Coral |
| D167 | SDRUM | Large | Light | 2432317.48 | 418907.56 | 42.1 | | Smooth Sand |
| D168 | MK106 | Medium | Light | 2432330.06 | 419613.93 | 17.1 | | Rubble & Sand w/Algae, Coral |
| D169 | ROCK275 | Small | Light | 2432336.29 | 419093.13 | 32.6 | | Rubble & Sand with Algae |
| D170 | PROJ554 | Medium | Medium | 2431900.9 | 420864 | 0.9 | | Sand Ripples |
| D171 | ROCK275 | Small | Light | 2432372.38 | 419400.74 | 23.3 | | Rubble & Sand |
| D172 | AM_BOX | Large | Medium | 2432387 | 419176.33 | 29.9 | | Rubble & Sand |
| D173 | ROCK7 | Large | Medium | 2432392.52 | 418985.76 | 35.9 | | Rubble & Sand |
| D174 | MK106 | Medium | Light | 2432401.15 | 418773.93 | 40.2 | | Rubble & Sand with Algae |
| D175 | MK76 | Medium | Medium | 2432427.59 | 418890.89 | 37.3 | | Rubble & Sand |
| D176 | ROCK275 | Small | Light | 2432427.95 | 418651.98 | 42.8 | | Rubble & Sand |
| D177 | ROCK275 | Small | Light | 2432423.02 | 419737.68 | 16.7 | | Sand Ripples |
| D178 | CASE40M | Small | Light | 2432456.8 | 419480.3 | 19.3 | | Rubble & Sand with Algae |
| D179 | CART554 | Medium | Medium | 2432488.99 | 419577.01 | 17.1 | | Rubble & Sand with Algae |
| D180 | PROJ554 | Medium | Medium | 2432510.69 | 419243.15 | 25.9 | | Smooth Sand |
| D181 | MK106 | Medium | Light | 2432539.29 | 418867.69 | 36.5 | | Rubble & Sand |
| D182 | 2ROCK5 | Medium | Medium | 2432540.99 | 419355.02 | 19.3 | | Rubble & Sand with Algae |
| D183 | 5APIPE | Medium | Light | 2432581.77 | 419092.54 | 26.2 | | Rubble & Sand |
| D184 | FRAG | Large | Heavy | 2432595.73 | 419607.97 | 16.6 | | Rubble & Sand with Algae |
| D185 | MK76 | Medium | Medium | 2432640.71 | 419459.14 | 17.8 | | Rubble & Sand with Algae |
| D186 | MK106 | Medium | Light | 2432670.48 | 419116.02 | 20.5 | | Rubble & Sand with Algae |
| D187 | MK76 | Medium | Medium | 2432691.91 | 419530.24 | 16.7 | | Rubble & Sand |
| D188 | ROCK5 | Medium | Medium | 2432697.49 | 419305.3 | 19 | | Rubble & Sand with Algae |
| D189 | ROCK275 | Small | Light | 2432698.37 | 419218.43 | 19.7 | | Rubble & Sand, Coral |
| D190 | LCHAIN | Medium | Medium | 2432817.59 | 419389.27 | 16.8 | | Sand Ripples |
| D191 | MK106 | Medium | Light | 2432850.07 | 419475.78 | 17.3 | | Rubble & Sand with Algae |
| D192 | MK76 | Medium | Medium | 2430881 | 421505.6 | 0 | | Sand Waves |
| D193 | 3SPIPE | Small | Light | 2431454 | 421051 | 0.9 | | Smooth Sand |

## D-4 Target Mapping and Classification Data for the Demonstration Area of the Range

Table D-4 contains the target detection and classification data reported by the demonstrators, and selected as-installed data corresponding to the detected targets. Multiple entries of the same site name are made in this table. When comparing the positions that the demonstrators reported for detected objects with the actual positions of installed targets, the closest target site to each reported detected object position was assigned. A total of 68 individual targets sites were assigned to the 88 object detection's made by the demonstrators in this area of the range.

Table D-4. Reported Target Detection and Classification Data for the Demonstration Area of the Range

| SITE NAME | TARGET SHORT NAME | NFESC CLASS (size, weight) | BURIAL DEPTH (meters) | SEAFLOOR TYPE (NFESC) | MMTC CLASS (size, weight) | POSITION ERROR (meters) |
|---|---|---|---|---|---|---|
| D001 | CART20M | Small, Light | | Smooth Sand | Medium, Medium (2) | 22.92 |
| D006 | MDRUM | Large, Medium | | Smooth Sand | Large, Heavy (1) | 41.31 |
| D009 | CHAIN | Medium, Medium | | Sand Ripples | Medium, Medium (2) | 64.86 |
| D010 | AM_BOX | Large, Medium | | Sand Ripples | Medium, Medium (2) | 27.01 |

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|---|---|---|---|---|---|---|
| D010 | AM_BOX | Large, Medium | | Sand Ripples | Medium, Medium (2) | 52.73 |
| D019 | ROCK5 | Medium, Medium | | Sand Ripples | Medium, Medium (2) | 85.94 |
| D019 | ROCK5 | Medium, Medium | | Sand Ripples | Medium, Medium (2) | 85.92 |
| D020 | 5APIPE | Medium, Light | | Sand Ripples | Medium, Medium (2) | 68.49 |
| D022 | 3SPIPE | Small, Light | | Sand Ripples | Medium, Medium (2) | 55.19 |
| D022 | 3SPIPE | Small, Light | | Sand Ripples | Medium, Medium (2) | 17.12 |
| D025 | CART20M | Small, Light | | Sand Ripples | Large, Heavy (1) | 71.18 |
| D026 | AM_BOX | Large, Medium | | Sand Ripples | Medium, Medium (2) | 33.47 |
| D028 | MK106 | Medium, Light | | Sand Ripples | Large, Heavy (1) | 62.65 |
| D029 | ROCK5 | Medium, Medium | | Sand Ripples | Large, Heavy (1) | 93.29 |
| D029 | ROCK5 | Medium, Medium | | Sand Ripples | Medium, Medium (2) | 23.68 |
| D032 | 4SPIPEL | Medium, Medium | | Smooth Sand | Medium, Medium (2) | 46.68 |
| D034 | ROCK275 | Small, Light | | Sand Ripples | Medium, Medium (2) | 30.22 |
| D035 | ROCK7 | Large, Medium | | Sand Ripples | Medium, Light (3) | 58.66 |
| D035 | ROCK7 | Large, Medium | | Sand Ripples | Large, Heavy (1) | 82.42 |
| D038 | MK82 | Large, Heavy | | Smooth Sand | Medium, Medium (2) | 44.30 |
| D039 | MK106 | Medium, Light | | Sand Ripples | Medium, Light (3) | 14.98 |
| D040 | PROJ554 | Medium, Medium | 0.1 | Sand Ripples | Medium, Light (3) | 121.93 |
| D043 | CART554 | Medium, Medium | | Rubble & Sand | Medium, Medium (2) | 88.12 |
| D047 | 2PROJ538 | Medium, Medium | | Rubble & Sand | Medium, Medium (2) | 19.81 |
| D048 | MK106 | Medium, Light | | Rubble & Sand | Medium, Medium (2) | 67.66 |
| D052 | MK106 | Medium, Light | | Rubble & Sand with Algae | Medium, Medium (2) | 85.55 |
| D057 | ROCK5 | Medium, Medium | | Rubble & Sand | Buried | 32.92 |
| D057 | ROCK5 | Medium, Medium | | Rubble & Sand | Medium, Medium (2) | 77.86 |
| D059 | CART20M | Small, Light | | Sand Ripples | Medium, Medium (2) | 30.71 |
| D060 | MK76 | Medium, Medium | | Sand Waves | Medium, Medium (2) | 94.06 |
| D067 | MDRUM | Large, Medium | | Rubble & Sand | Buried | 18.56 |
| D068 | PROJ554 | Medium, Medium | | Rubble & Sand | Medium, Medium (2) | 29.46 |
| D079 | CART554 | Medium, Medium | | Rubble & Sand, Coral | Medium, Medium (2) | 61.84 |
| D080 | PROJ554 | Medium, Medium | | Sand Ripples | Buried | 69.66 |
| D081 | ROCK5 | Medium, Medium | | Sand Waves | Buried | 52.05 |
| D086 | CASE40M | Small, Light | | Smooth Sand | Medium, Light (3) | 48.13 |
| D090 | FRAG | Large, Heavy | | Rubble & Sand with Algae | Medium, Light (3) | 97.91 |
| D092 | CART762 | Small, Light | | Rubble & Sand | Large, Heavy (1) | 44.02 |
| D092 | CART762 | Small, Light | | Rubble & Sand | Medium, Light (3) | 55.60 |
| D093 | GRATE | Large, Medium | | Rubble & Sand with Algae | Medium, Light (3) | 98.06 |
| D096 | 5APIPE | Medium, Light | | Smooth Sand | Medium, Medium (2) | 44.44 |
| D096 | 5APIPE | Medium, Light | | Smooth Sand | Large, Heavy (1) | 119.52 |
| D101 | CART554 | Medium, Medium | | Rubble & Sand | Medium, Medium (2) | 169.22 |
| D105 | LCHAIN | Medium, Medium | | Rubble & Sand | Medium, Medium (2) | 45.87 |
| D105 | LCHAIN | Medium, Medium | | Rubble & Sand | Medium, Medium (2) | 38.45 |
| D106 | CART554 | Medium, Medium | | Rubble & Sand | Medium, Medium (2) | 39.22 |
| D107 | MK106 | Medium, Light | | Rubble & Sand with Algae | Medium, Light (3) | 52.23 |
| D107 | MK106 | Medium, Light | | Rubble & Sand with Algae | Medium, Medium (2) | 116.19 |
| D109 | ROCK7 | Large, Medium | | Rubble & Sand | Medium, Medium (2) | 49.32 |
| D111 | CART554 | Medium, Medium | | Smooth Sand | Medium, Medium (2) | 113.10 |
| D113 | LCHAIN | Medium, Medium | 0.1 | Sand Ripples | Large, Heavy (1) | 28.95 |
| D119 | ROCK275 | Small, Light | | Smooth Sand | Medium, Light (3) | 53.18 |
| D119 | ROCK275 | Small, Light | | Smooth Sand | Medium, Medium (2) | 67.58 |
| D125 | 4SPIPE | Medium, Medium | | Rock Outcrop Flat | Medium, Medium (2) | 57.62 |
| D125 | 4SPIPE | Medium, Medium | | Rock Outcrop Flat | Large, Heavy (1) | 72.26 |
| D127 | 3MK106 | Medium, Light | | Rubble & Sand | Medium, Light (3) | 134.32 |
| D128 | 3MK106 | Medium, Light | | Rubble & Sand | Medium, Medium (2) | 131.15 |
| D131 | CASE40M | Small, Light | | Rubble & Sand | Medium, Light (3) | 27.31 |
| D138 | ROCK5 | Medium, Medium | | Rubble & Sand with Algae | Medium, Medium (2) | 76.07 |
| D138 | ROCK5 | Medium, Medium | | Rubble & Sand with Algae | Medium, Medium (2) | 205.45 |
| D138 | ROCK5 | Medium, Medium | | Rubble & Sand with Algae | Medium, Medium (2) | 176.57 |

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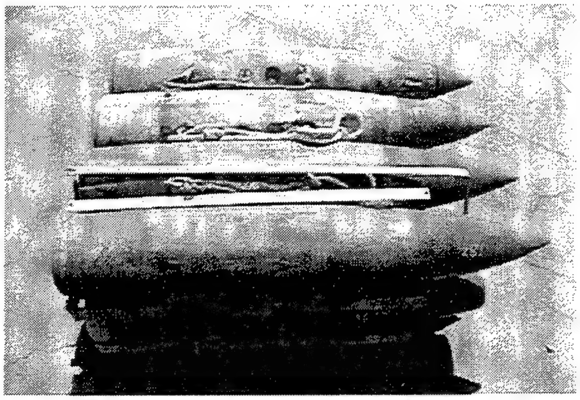
|---|---|---|---|---|---|---|
| D139 | 4SPIPE | Medium, Medium | | Sand Ripples | Medium, Light (3) | 20.53 |
| D141 | MK82 | Large, Heavy | | Rock Outcrop Flat | Medium, Medium (2) | 103.47 |
| D141 | MK82 | Large, Heavy | | Rock Outcrop Flat | Medium, Medium (2) | 97.23 |
| D141 | MK82 | Large, Heavy | | Rock Outcrop Flat | Medium, Medium (2) | 29.82 |
| D144 | 3SPIPE | Small, Light | | Rubble & Sand with Algae | Large, Heavy (1) | 153.62 |
| D145 | CASE40M | Small, Light | | Rubble & Sand with Algae | Medium, Medium (2) | 100.57 |
| D146 | ROCK7 | Large, Medium | | Smooth Sand | Medium, Medium (2) | 66.51 |
| D146 | ROCK7 | Large, Medium | | Smooth Sand | Medium, Medium (2) | 158.44 |
| D149 | 3MK106 | Medium, Light | | Rubble & Sand | Medium, Medium (2) | 24.43 |
| D155 | MK106 | Medium, Light | | Rubble & Sand with Algae | Medium, Medium (2) | 64.49 |
| D158 | MK81 | Large, Heavy | | Smooth Sand | Medium, Light (3) | 51.28 |
| D158 | MK81 | Large, Heavy | | Smooth Sand | Medium, Light (3) | 33.21 |
| D160 | MK81 | Large, Heavy | | Sand Ripples, Rock Outcrop | Medium, Medium (2) | 24.19 |
| D164 | 4SPIPE | Medium, Medium | | Rubble & Sand with Algae | Medium, Medium (2) | 47.56 |
| D171 | ROCK275 | Small, Light | | Rubble & Sand | Medium, Medium (2) | 16.07 |
| D172 | AM_BOX | Large, Medium | | Rubble & Sand | Medium, Light (3) | 81.76 |
| D172 | AM_BOX | Large, Medium | | Rubble & Sand | Medium, Medium (2) | 49.02 |
| D173 | ROCK7 | Large, Medium | | Rubble & Sand | Medium, Light (3) | 72.85 |
| D174 | MK106 | Medium, Light | | Rubble & Sand with Algae | Medium, Medium (2) | 63.00 |
| D178 | CASE40M | Small, Light | | Rubble & Sand with Algae | Medium, Medium (2) | 79.74 |
| D180 | PROJ554 | Medium, Medium | | Smooth Sand | Medium, Medium (2) | 34.25 |
| D181 | MK106 | Medium, Light | | Rubble & Sand | Medium, Medium (2) | 130.24 |
| D181 | MK106 | Medium, Light | | Rubble & Sand | Medium, Medium (2) | 83.11 |
| D182 | 2ROCK5 | Medium, Medium | | Rubble & Sand with Algae | Large, Heavy (1) | 94.91 |
| D183 | 5APIPE | Medium, Light | | Rubble & Sand | Large, Heavy (1) | 72.17 |
| D189 | ROCK275 | Small, Light | | Rubble & Sand, Coral | Large, Heavy (1) | 51.00 |
| D190 | LCHAIN | Medium, Medium | | Sand Ripples | Large, Heavy (1) | 92.78 |

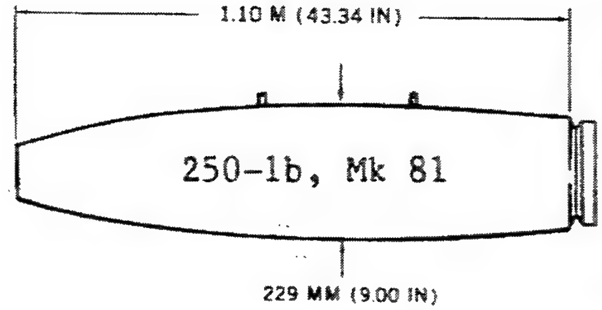
## APPENDIX E

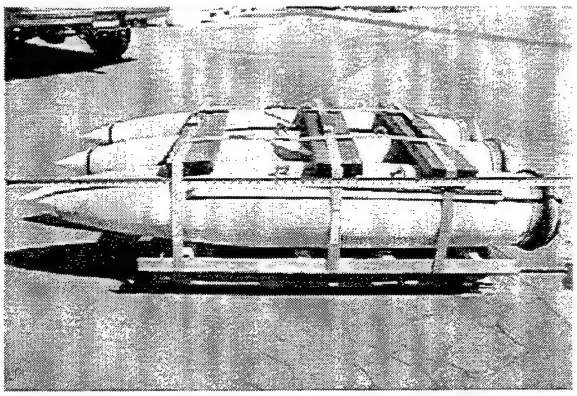
## TARGET IDENTIFICATION GUIDE

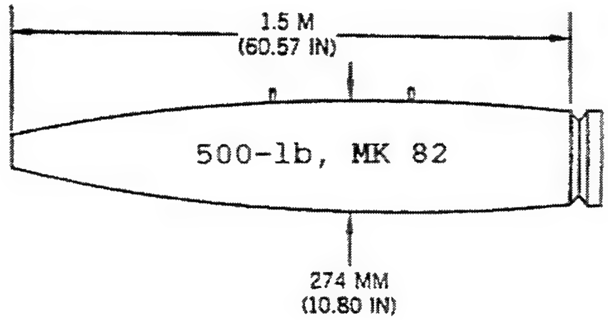
This appendix provides the physical description along with a photograph of all inert ordnance and false targets installed in the SMTC range. Multiple pieces of each target were installed. Appendix D provides the installed target database. All inert targets were clearly marked INERT. A serial number and NFESC plane number were inscribed on each target in case they were inadvertently washed on shore or picked up by a fishing vessel. All targets recovered after range operations had been completed and were stored for later use on subsequent demonstrations.

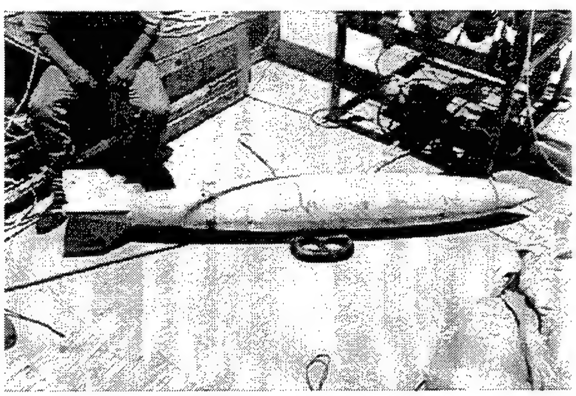
# MK81, MK82, & MK83
# PRACTICE BOMBS



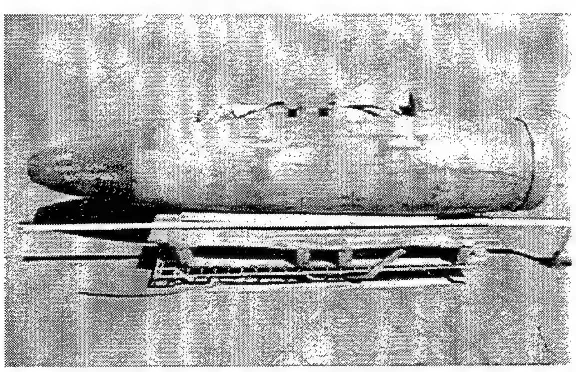


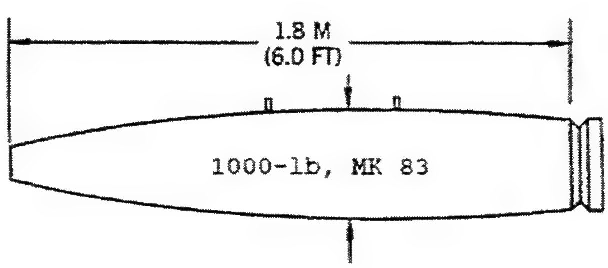





MK82 Practice Bomb as installed.
Length with tail fin: 91"



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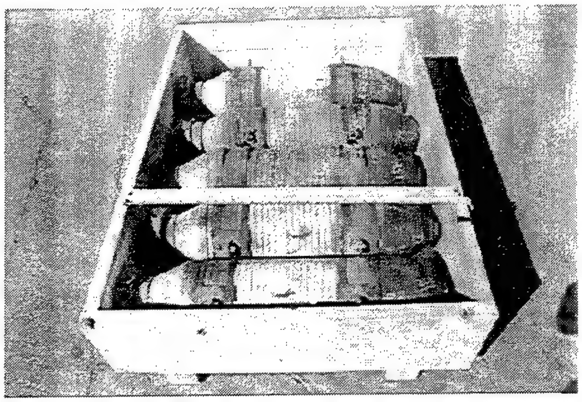
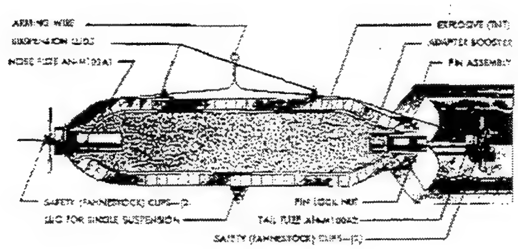
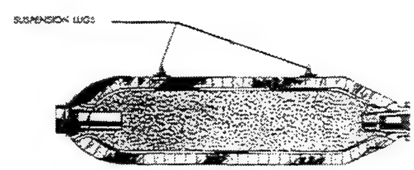
# AN-M88 FRAG BOMB
# MK76 PRACTICE BOMB



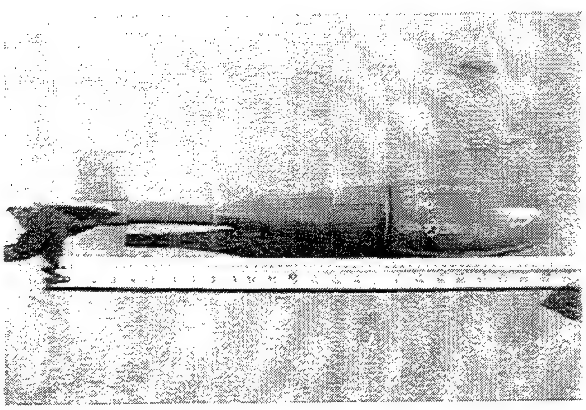


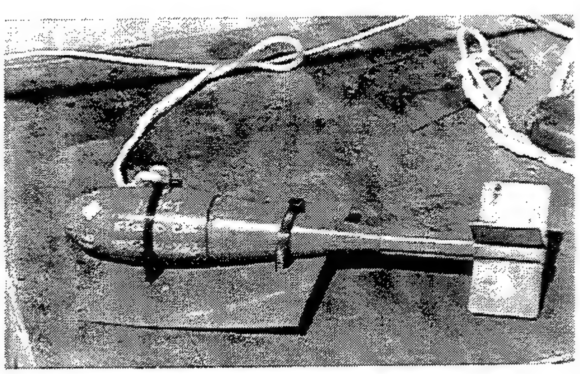

<u>Fragmentation Bomb</u>

Weight: 217 lb.
Diameter: 8"
Length: 33.5"



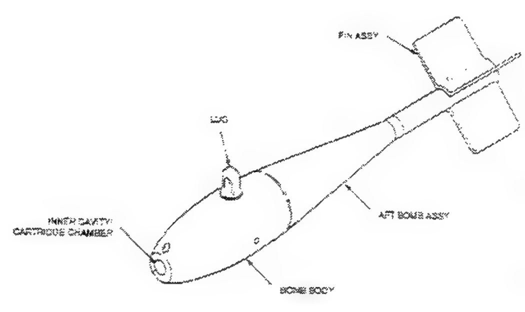

Fragmentation bomb as deployed





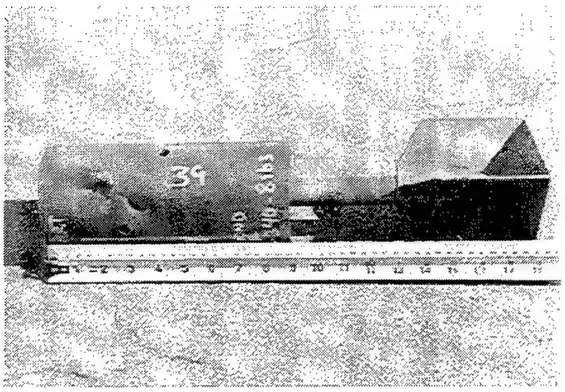
<u>MK76 Practice Bomb</u>

Weight: 24 lb.
Diameter: 6.625"
Length: 25"

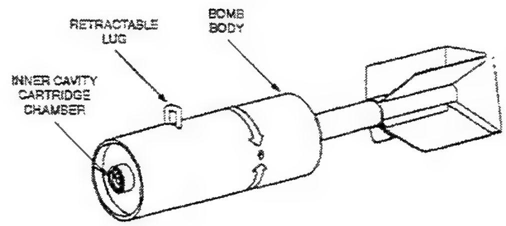


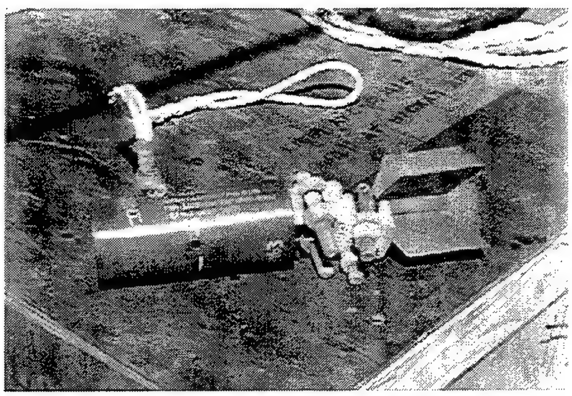

MK76 Practice Bomb with plastic fairing and lifting pendant.

# MK106 PRACTICE BOMB

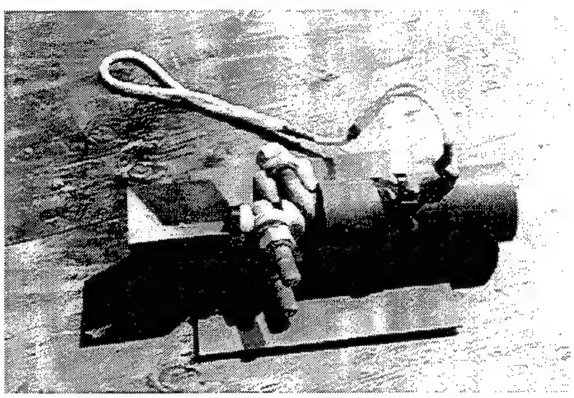


MK106 Practice Bomb
Weight: 4 lb.
Diameter: 5.5"
Length: 18.5"

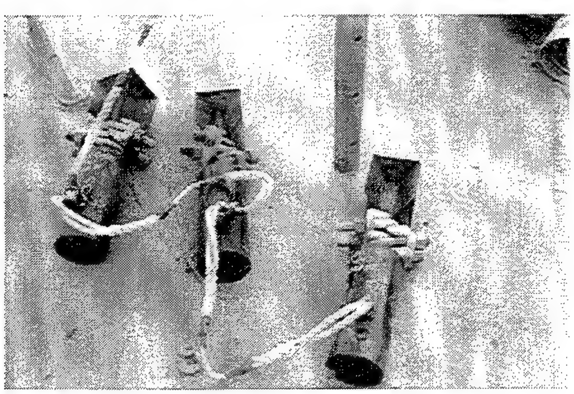


MK106 Practice Bomb with clips added for weight.

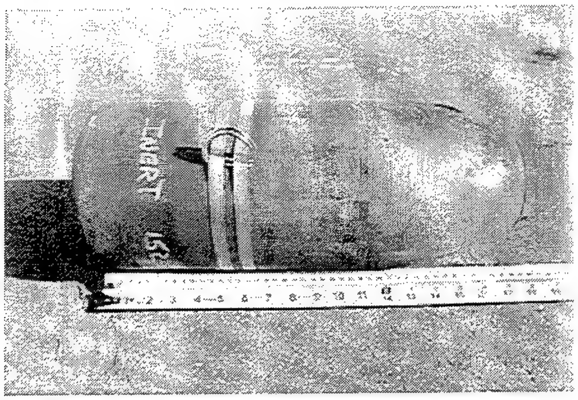


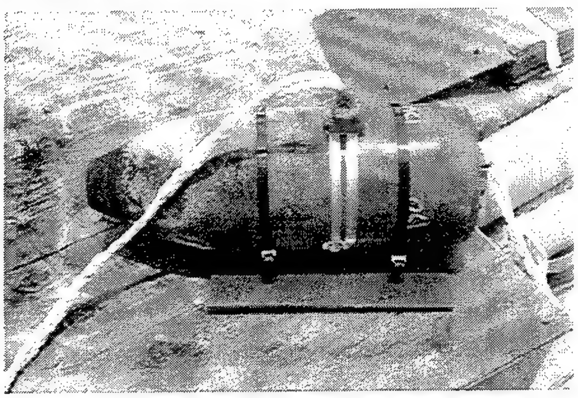
MK106 Practice Bomb with clips and plastic fairing.

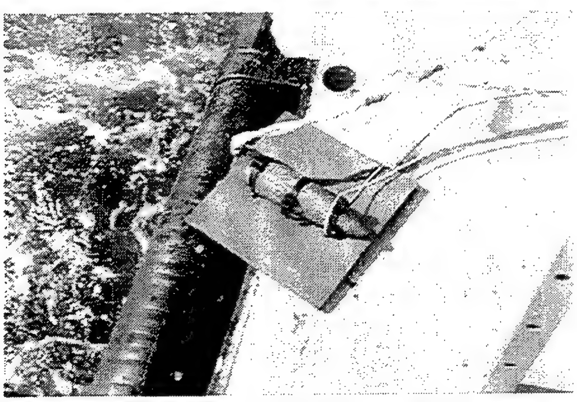


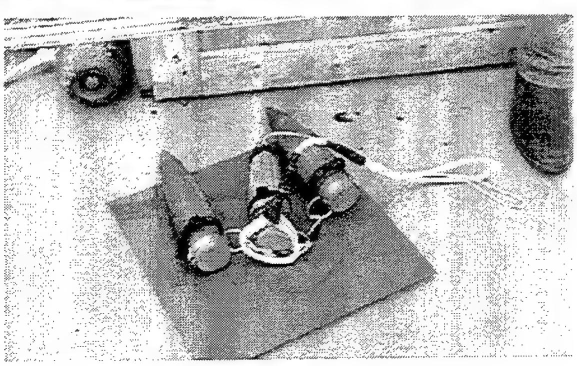
MK106 in multiple unit group.

# MK5 7.2" ROCKET WARHEAD
# MK1 2.75" PRACTICE ROCKET WARHEAD



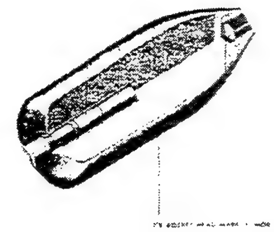




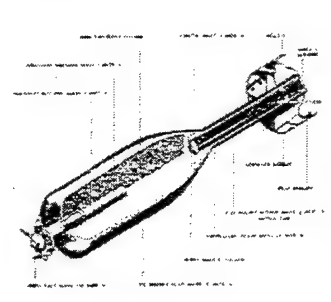


<u>7" Rocket Warhead</u>
(with plastic fairing)
Weight: 47.5 lb.
Diameter: 7"
Length: 23"

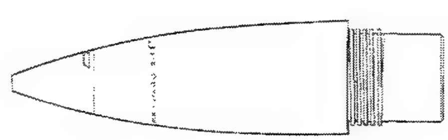
7" Rocket
as deployed:



7" Rocket warhead actual configuration

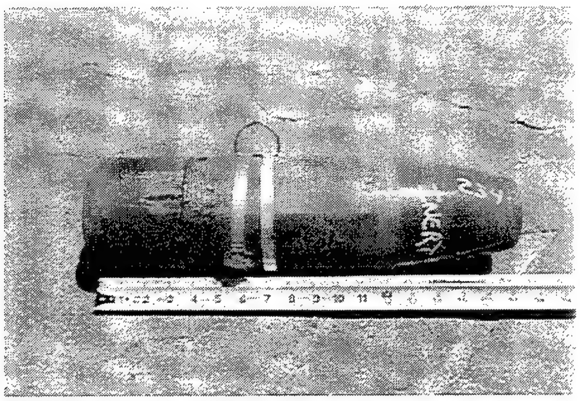


<u>2.75" Rocket Warhead</u>
Weight: 6 lb.
Diameter: 2.75"
Length: 11"

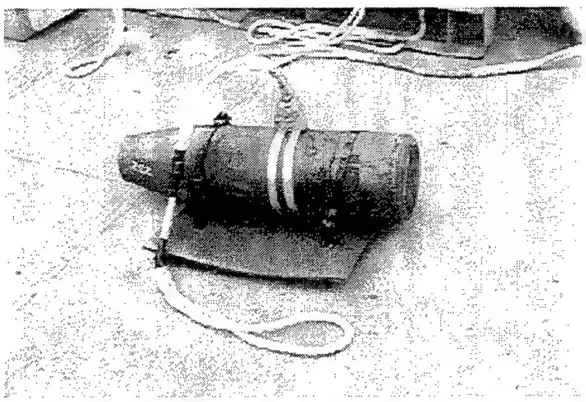


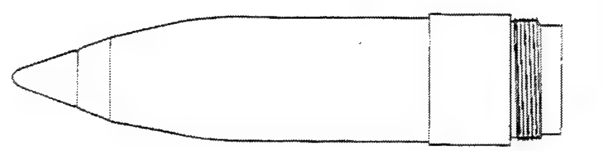
2.75" Warhead in multiple unit group with plastic fairing.

# MK6 5" PRACTICE ROCKET WARHEAD
# MK41 5" 54 CALIBER PROJECTILE

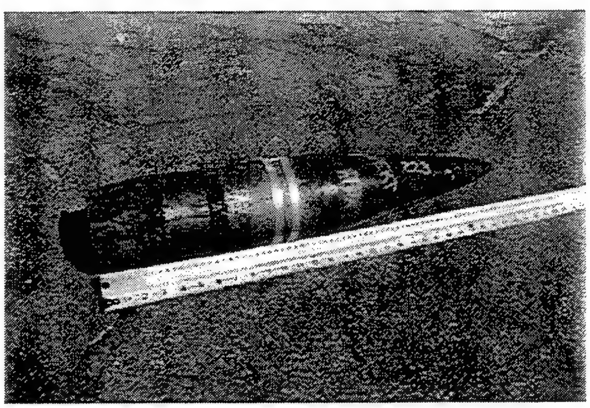


5" Rocket Warhead
Weight: 38 lb.
Diameter: 5"
Length: 18"

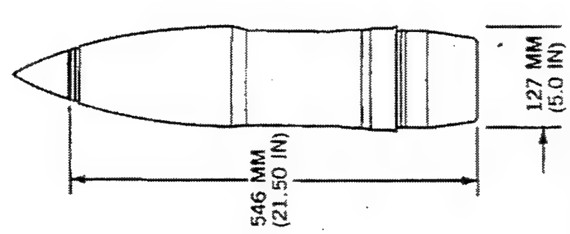


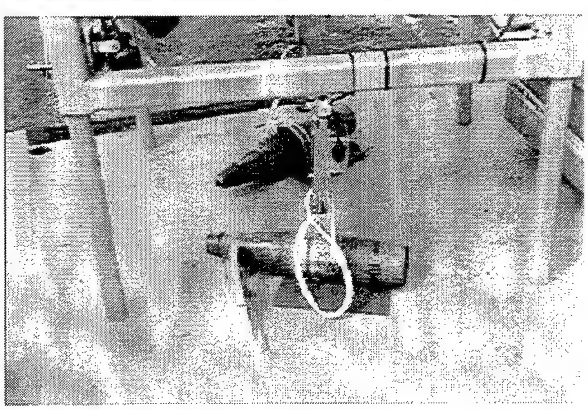


5" Rocket Warhead as installed with plastic fairing and pendant.



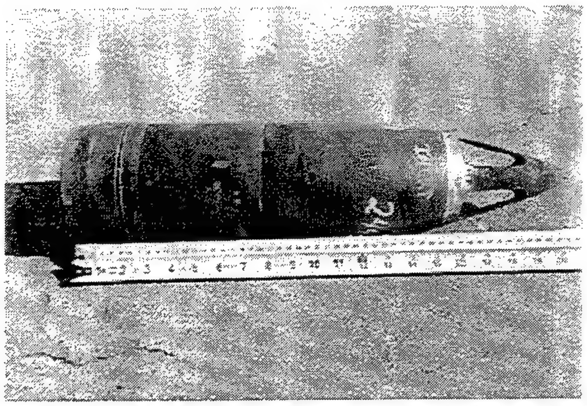
5" 54 Cal. Projectile
Weight: 70 lb.
Diameter: 5"
Length: 26.25"



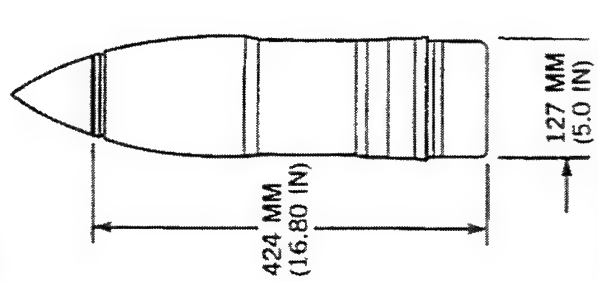
5" 54 Projectile as installed with plastic fairing and pendant.

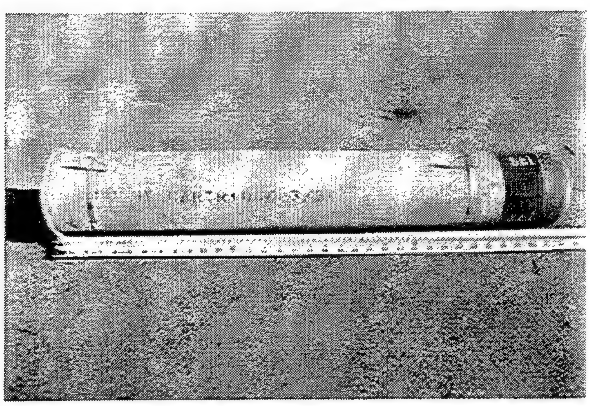
# MK38 5" 38 CALIBER PROJECTILE
# 5" 54 CALIBER DUMMY CARTRIDGE



<u>5" 38 Cal. Projectile</u>

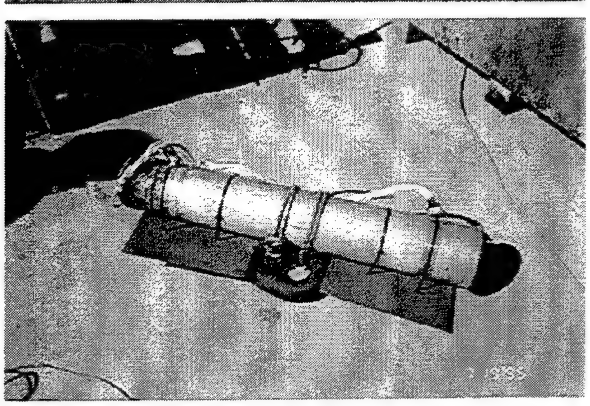
Weight: 55 lb.
Diameter: 5"
Length: 21"

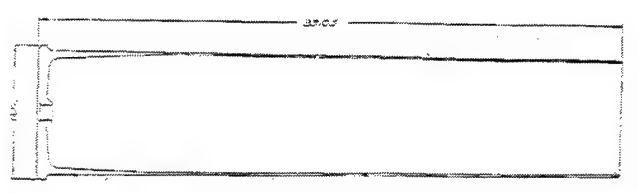


<u>5" 54 Cal. Cartridge</u>

Weight: 15 lb.
Diameter: 5"
Length: 35"



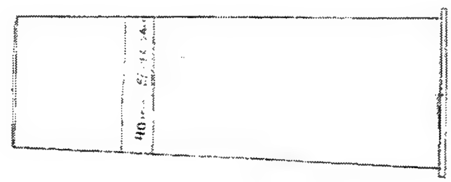


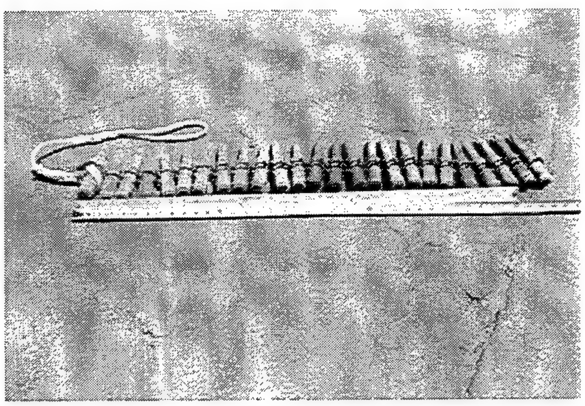
5" 54 Cal. Cartridge as installed with link added for weight, pendants, and plastic fairings.

# 40MM SALUTE CARTRIDGE
# DUMMY 20MM CARTRIDGE
# DUMMY 7.62MM CARTRIDGE

40mm Cartridge (five per group)

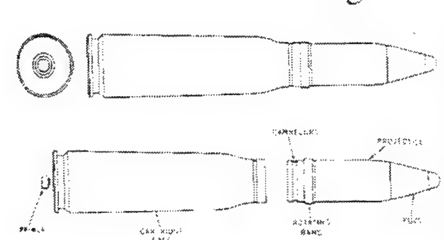
| Each round | | Each group | |
|---|---|---|---|
| Weight: | 1 lb. | Weight: | 6 lb. |
| Diameter: | 2.45" | Width: | 2.45" |
| Length: | 8.75" | Length: | 8.75" |
| | | Height: | 19" |

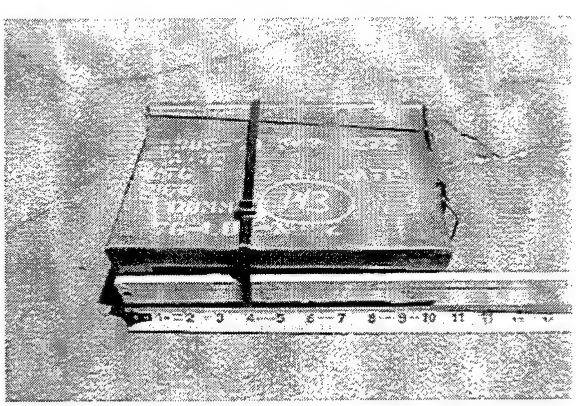




20mm Cartridge (25 rounds linked)

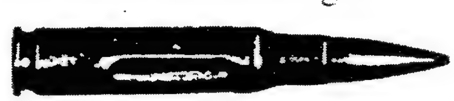
| Each round | | Each group | |
|---|---|---|---|
| Weight: | 0.6 lb. | Weight: | 15 lb. |
| Diameter: | 1.125" | Width: | 1.5" |
| Length: | 6.625" | Length: | 6.625" |
| | | Height: | 40.5" |





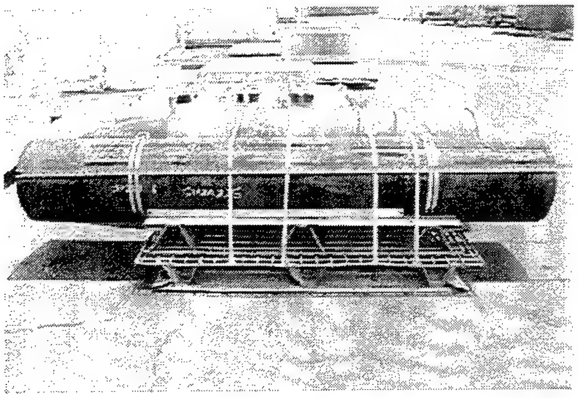
7.62mm Cartridge (66 rounds in ammo box)

| Each round | | In ammo box | |
|---|---|---|---|
| Weight: | 0.06 lb. | Weight: | 6 lb. |
| Diameter: | 0.4375" | Length: | 10.75" |
| Length: | 2.75" | Width: | 3.75" |
| | | Height: | 7.25" |

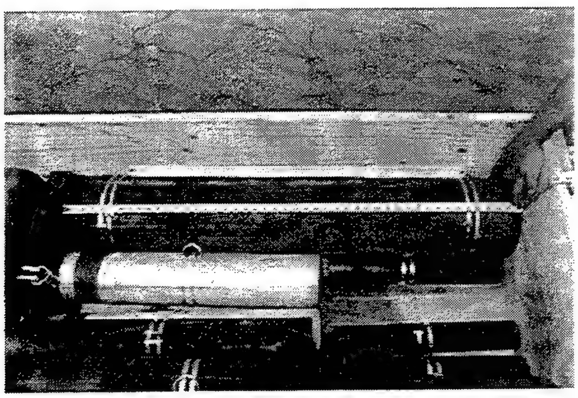


DUMMY

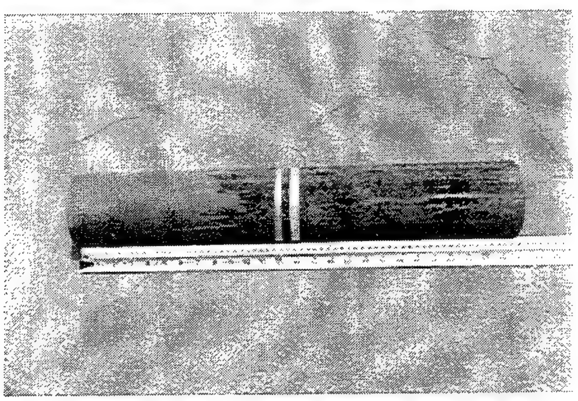
# FALSE TARGETS - LARGE STEEL PIPE



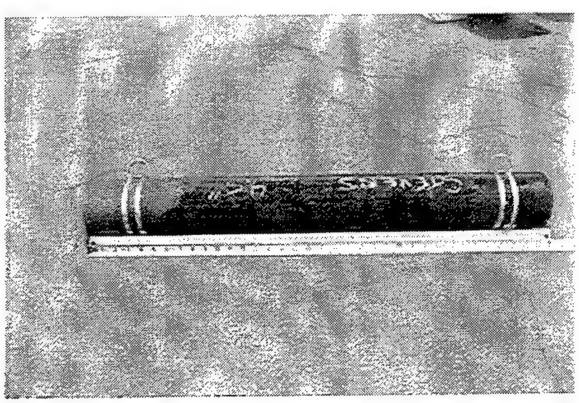
12" Diameter Steel Pipe
Weight: 314 lb.
Diameter: 12.75"
Length: 76"



8" Diameter Steel Pipe
Weight: 110 lb.
Diameter: 8.625"
Length: 92.625"

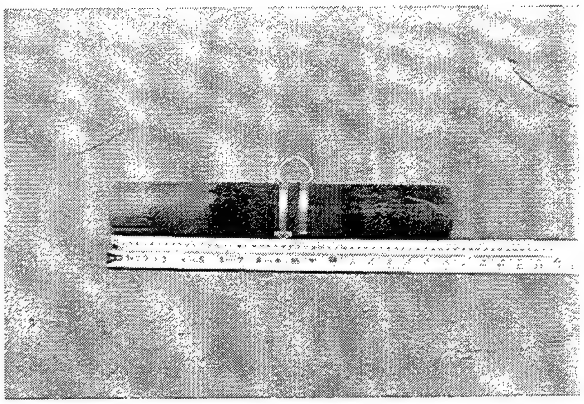


4" Diameter Steel Pipe
Weight: 24 lb.
Diameter: 4.5"
Length: 26"

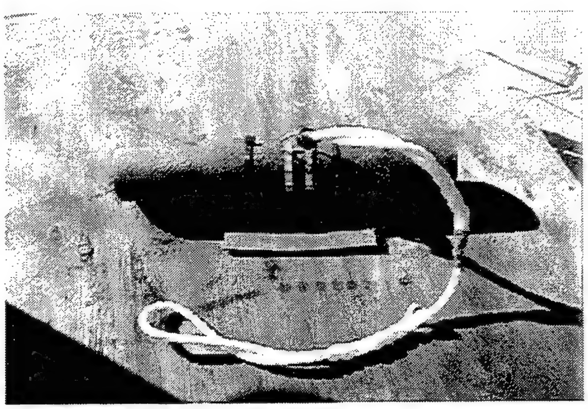


4" Diameter Steel Pipe
Weight: 33 lb.
Diameter: 4.5"
Length: 35.625"

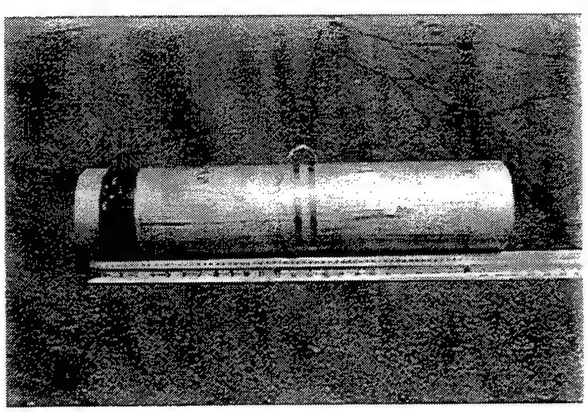
# FALSE TARGETS - SMALL DIAMETER STEEL AND ALUMINUM PIPE



<u>3" Steel Pipe</u>
Weight: 8 lb.
Diameter: 3.875"
Length: 18"

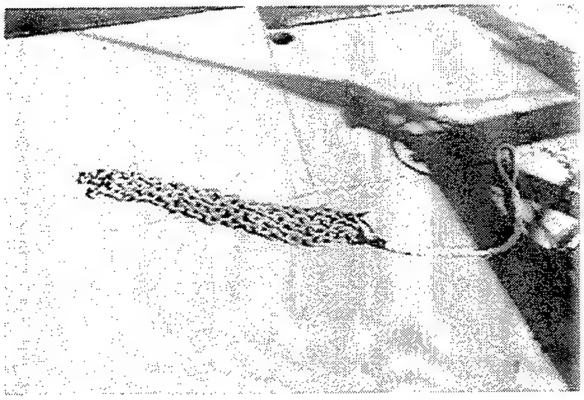


<u>3" Steel Pipe</u> with plastic fairing.

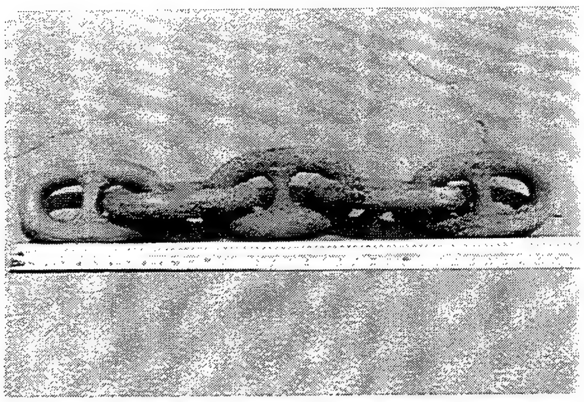


<u>5" Aluminum Pipe</u>
Weight: 16 lb.
Diameter: 5.75"
Length: 26.5"

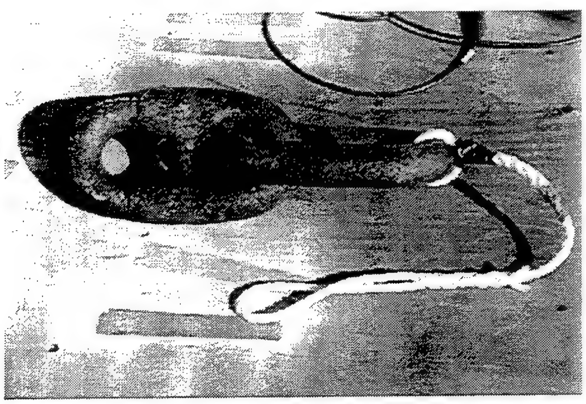
# FALSE TARGETS - CHAIN



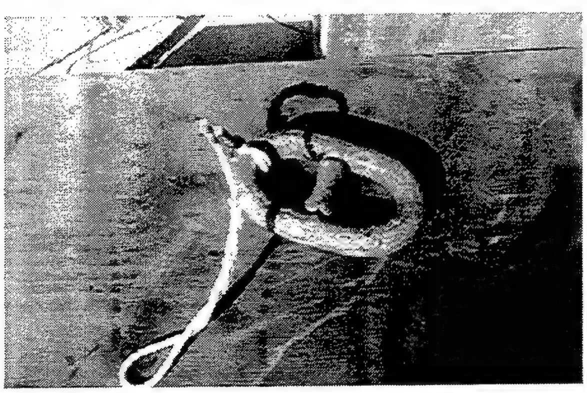
Long Chain
Weight: 20 lb.
Length: 40"
Width: 6"
Height: 1.5"



5 Link Chain
Weight: 68 lb.
Length: 47.5"
Width: 5"
Height: 1.625"



2 Link Chain
Weight: 25 lb.
Length: 24"
Width: 6"
Height: 4"



Chain Link
Weight: 25 lb.
Length: 18"
Width: 8"
Height: 3"

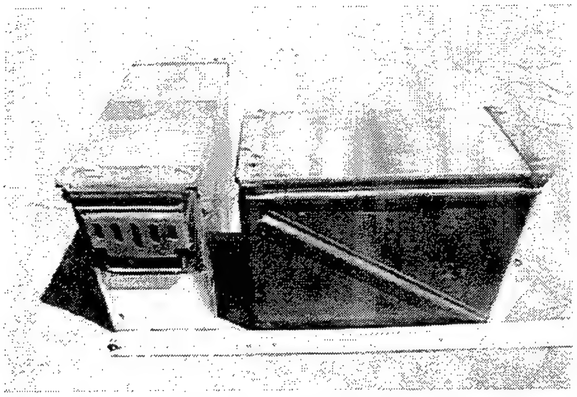
# FALSE TARGETS - STEEL DRUMS

<u>Large Steel Drum</u>
(filled with sand)
Weight: 200 lb.
Diam: 19.75"
Height: 21.5"

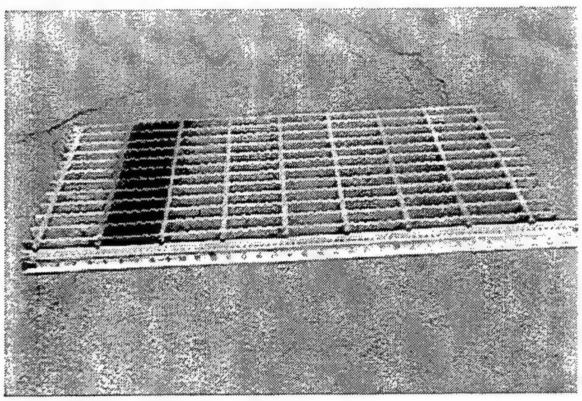
<u>Medium Steel Drum</u>
(filled with scrap steel)
Weight: 35 lb.
Diam: 11.5"
Height: 18.5"

<u>Small Steel Drum</u>
(filled with scrap steel)
Weight: 15 lb.
Diam: 7.5"
Height: 9.5"

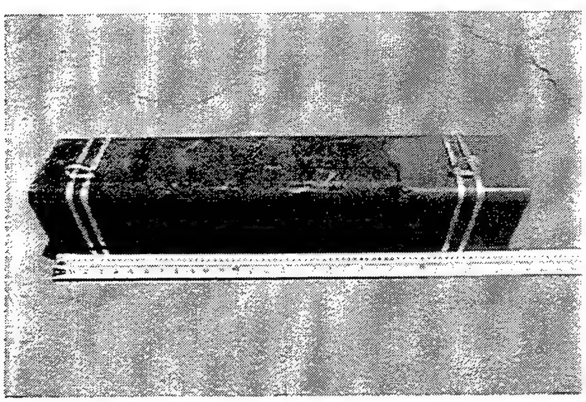
# FALSE TARGETS - MISCELLANEOUS SHAPES



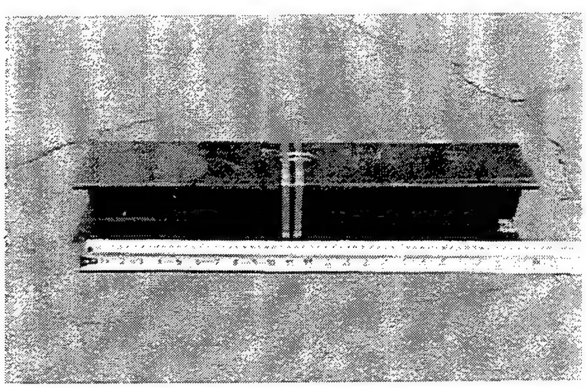
Ammunition Box
(filled with scrap steel)
Weight: 35 lb.
Length: 9.25"
Width: 18.25"
Height: 12.75"



Steel Grating
Weight: 37 lb.
Length: 34.75"
Width: 14.125"
Height: 1.5"



6" Square Tube
Weight: 53 lb.
Length: 29.625"
Width: 6"
Height: 6"



Steel I-Beam
Weight: 26 lb.
Length: 23.625"
Width: 4.375"
Height: 3.5"

## APPENDIX F

## MMTC FINAL REPORT: LOCATION OF ORDNANCE-LIKE OBJECTS IN COASTAL WATER TO DEPTHS OF 50 METERS

FINAL PROJECT RESULTS
FOR
U.S. NAVAL FACILITIES ENGINEERING SERVICE CENTER
560 CENTER DRIVE
PORT HUENEME, CA 93043-4328 USA

IN PARTIAL FULFILLMENT OF ONR GRANT N00014-95-1-0828

# LOCATION OF ORDNANCE-LIKE OBJECTS IN COASTAL WATERS TO DEPTHS OF 50 METERS

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JUNE 30, 1996

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# LOCATION OF ORDNANCE-LIKE OBJECTS IN COASTAL WATERS TO DEPTHS OF 50 M

## INTRODUCTION

Many coastal marine sites in the tropical Pacific and elsewhere were the sites of intensive fire fights during World War II, and others were subsequently used over extended periods by the U.S. armed services and allies as training areas for simulated warfare using live ordnance. The reduction of defense needs has resulted in the termination of many of these activities and some of the islands and their surrounding environs are scheduled to be cleaned up and returned to public use.

Identified ordnance discarded in offshore areas includes naval shells, bombs, rockets, torpedoes, mortar rounds, and small arms ammunition, much of it unexploded and some of it buried upon impact or subsequently by sedimentary processes. In some sites the Navy has delineated a 2-mile danger zone around the coast, but it is generally understood that areas designated for immediate clean-up extend only to the 50-meter isobath, since common usage of the seabed, and the associated risks of interactions with such objects, do not extend significantly to deeper waters except for the occasional deep-water fishing trawler.

The Marine Minerals Technology Center (MMTC) has for the last six years been developing techniques for quantitative mapping of seabed mineral deposits. An important class of seabed minerals is the placer deposit, consisting of concentrations of relatively dense minerals, such as gold, tin, and others, which are sorted naturally by wave and current action into shallow seabed accumulations. These deposits are generally not easy to find and exploit because they are small and their occurrence is notoriously difficult to predict using available geological and engineering models.

This pursuit has led MMTC to develop a number of tools and techniques which can be used with relatively small investment to improve the odds of finding and mapping these deposits. In key respects, placers are similar to ordnance in that they are smaller than most geological structures and consist of anomalous concentrations of specific materials in sites which are not easy to predict. The methods developed by MMTC and their collaborators for placers can provide cost effective means for finding and classifying ordnance. The objective of this project is to demonstrate this technology on an appropriate scale to facilitate their removal, destruction, or other remediation.

## ORGANIZATION

The project was completed using the talents and facilities of the following groups, organized as follows.

The **Marine Minerals Technology Center, Ocean Basins Division** (MMTC/OBD) is a part of the Center for Ocean Resource Technology under the Hawai'i Natural Energy Institute within

the School of Ocean and Earth Science and Technology at the University of Hawai'i. Its Associate Director, Dr. Charles L. Morgan, served as Principal Investigator of this project and worked closely with the co-investigator, Dr. Michael J. Cruickshank, Director of MMTC/OBD, to oversee all aspects of the work. MMTC provided all the equipment, through former acquisition, lease or purchase, to complete the project. MMTC/OBD is responsible for all deliverables to the Naval Facilities Engineering Service Center (NFESC) and for the management of the following project team members.

**Oceanic Imaging Consultants** (OIC) is an independent consulting firm located at the Manoa Innovation Center in Honolulu, Hawai'i. OIC subcontracted directly with MMTC/OBD to develop and test the the side-scan sonar system and to generate the primary target location and classification predictions using all available data.

The **Marine Minerals Technology Center, Continental Shelf Division** (MMTC/CSD), is the affiliated academic research center with MMTC/OBD and is located at the University of Mississippi. MMTC/CSD subcontracted directly with MMTC/OBD for its participation in this project. Mr. Douglas Lockhart, Senior Staff Engineer for MMTC/CSD, worked closely with Dr. J. Robert Woolsey, Director of MMTC/CSD is reporting directly to MMTC/OBD. MMTC/CSD provided the differential GPS navigation and sub-seafloor reflection profiling system.

This report summarizes the key results of this project, and it presents recommendations for future work in this area. The systems evaluated include the following:

1. Navigation and location tools, specifically the differential global positioning system (DGPS) supplied by NFESC, Nautronix® short-baseline system, and Winfrog® integration software, as well as the leased TSS® ship-motion compensator.

2. Reson® SeaBat® multi-channel shallow bathymetric mapping system.

3. MMTC side-scan sonar system which includes: 1) the EdgeTech (formerly EG&G) EG&G DF-1000® 100 kHz and 500 kHz towfish and digital conversion unit and 2) two data acquisition systems (the GEODAS, supplied on a Sun® workstation platform by OIC, and the Elics® Delph Sonar program on a PC-compatible computer supplied by MMTC/CSD.

4. Advanced Airborne Hyperspectral Imaging System (AAHIS), supplied by the contractor SETS Technology, Inc.

5. Fisher® Pulse 12® time-domain electromagnetic pulse sensor, provided by MMTC/OBD.

6. Sea Engineering, Inc.®/Precision Signal® broadband, frequency modulated "chirp" shallow-reflection sonar profiler, as received both by the system itself and by the MMTC/CSD surface acoustic array.

7. The EG&G® GeoPulse® impulse reflection profiler sound source, as received by the MMTC/CSD array.

The original project schedule was to have produced three reports: 1) a quick look assessment due immediately following the at-sea activities in August, 2) a list of final target identifications and locations, as well as a transfer of the complete set of target locations and identifications to MMTC by the end of October, and a final report of the project, which was due by December 31, 1995. Technical problems ensued (see below), and MMTC was not able to deliver the quick-look or the final report as planned. As a result, a no-cost extension was granted to MMTC allowing more time for analyzing the survey results to address the major project goals of assessing conventionally available systems for potential use for unexploded ordnance (UXO) location and classification.

Included for each system are: 1) a description with the operational configuration used in the survey; 2) the principal investigator's current overall assessment of the system capabilities to address the project objectives and where appropriate, examination of the discrepancies between the results of the survey and the actual locations and classifications of the targets deployed by NFESC; 3) descriptions of data products delivered; and 4) relevant operational notes.

## NAVIGATION SYSTEMS

### System Description

All of the navigation data collection systems used on this vessel were owned by NFESC, and were operated by Pelagos or MMTC personnel during the MMTC operations. The primary surface navigation system used on the *M/V American Islander* during the range operations was of Novatek Model #311R global positioning system (GPS) receiver, used in differential mode (DGPS). A Nautronix S04 ultra-short baseline (USBL) acoustic tracking system (ATS) was the primary system used for subsurface navigation and object tracking. Acoustic USBL beacons were used on demonstration hardware for subsea tracking. A KVH model 314AC azimuth digital compass provided ship-heading information.

Pelagos Winfrog® integrated navigation software was used on a project computer to integrate surface navigation, subsurface navigation and tracking, and compass data for real-time display and documentation. Navigation and target spreadsheet data were saved to computer hard drive and diskettes periodically during each day of operations. Navigation data were reported directly from the NFESC navigation computer to the MMTC data collection systems.

### Overall Assessment

With one important exception, these systems performed very well and provided the necessary data for target location. The DGPS performed flawlessly with no significant downtime. Ship and airplane positions collected are believed to be accurate to <5 m, based upon positions retrieved on the beach at known locations. The ship-motion compensator also performed well and greatly improved the quality of the bathymetric data obtained, with some phasing problems, noted below. The navigation integration software proved to be well designed and capable of efficiently collecting and reducing the key navigation data and reporting the reduced results to

all of the data acquisition platforms. The navigation consultants from Pelagos® Corporation did an outstanding job in implementing the collection and reporting procedures on the ship as well as assisting in the interfacing of the DGPS system with the SETS Technology, Inc. airborne system.

Unfortunately, as discussed below in the operational notes for navigation and again more specifically for each sensor, the USBL did not interface well with the acoustic sensors and placed severe limits on the navigational accuracy of corresponding results for these systems.

**Data Analysis**

Analysis of the navigation data will be addressed below for each system. MMTC recorded the primary satellite range data, ship motions, and USBL-generated offsets as well as the inferred target locations.

**Operational Notes**

1. Significant acoustic cross-talk was observed between the USBL transponder signal and the side-scan receivers, causing unacceptable noise on the side-scan records and precluding continuous operation in the transponder mode.

2. In the responder mode, poor tracking of the deployed system was observed, particularly when the system was close to the ship in shallow water depths. Some signal responses were obtained in the relatively deep deployments.

3. No offsets could be determined with the USBL system for the surface-towed acoustic hydrophone arrays.

## MULTI-CHANNEL BATHYMETRIC MAPPING

**System Description**

Bathymetry was obtained using the Reson, Inc. SeaBat® 9001 Multibeam Bathymetric Sonar System. This is the most compact, light-weight multi-channel sonar currently available on a commercial lease. It surveys over a swath of 90° across track (45° above vertical to port and starboard) with individual beam widths of 1.5°. It can be operated either from a towed or hull-mounted platform, and can be used in shallow water in water depths $>5$ m to 600 m. To accommodate for the motions of the survey vessel, TSS, Inc. pitch, roll, and heave sensors were also deployed simultaneously. The equipment and its use in this survey were all conventional.

**Overall Assessment**

The SeaBat® produced excellent bathymetric data which were readily integrated into the acquisition process. The data are very consistent from line to line and appear to be accurate to

within about 2-m water depth, with horizontal resolutions of a few meters. The system is a good complement to the side-scan sonar, producing quantitative data to remove some of the ambiguity of the time-series returns received by the side-scan system.

**Data Analysis**

OIC developed a logging/processing package for real-time integration of sonar, attitude and navigation data. The same package was used in post-processing to re-process the data for elimination of outliers and attitude-induced artifacts. Three problems had to be dealt with in re-processing the multibeam data: multiples and noncoherent noise, aberrant attitude and a lag between attitude and sonar data.

Multiples and random noise manifested themselves as large "delta-function" offsets in the cross-track bathymetry profits. While isolated spikes were thought to be due to noise in the water, the multiples were the result of echoes from previous pings "wrapping around" into the current "ping," obfuscating real arrivals and adding > 20m of coherent error to the data. Multiples corrupted approximately 10 to 15 percent of the data, and could probably be avoided in the future by more aggressive system-gain adjustments.

The attitude package supplied with the multibeam provided pitch, roll, and heave measurements for the vessel, which were to be used to correct the raw multibeam data to produce final bathymetry profiles. While in general this system performed admirably, as indicated by the quality of our final bathymetry, it would from time to time drift significantly, providing roll and pitch values in excess of 20 degrees, and heave in excess of 5 meters. Given the sheltered nature of the survey, and the participants recollections, such variations seemed unlikely, and required that we add an ability to mark such degraded data "bad".

Finally, while most of the attitude and sonar data were usable, it became apparent that they were not arriving at the same time. On average, attitude appeared to lag the sonar data by 3 to 6 pings, which if uncompensated would have resulted in the application of the wrong attitude correction. The bathymetric data presented here have been adjusted to accommodate for this effect by applying appropriate time delays to the data.

Folio No. 1 and Figure 1 present the resultant bathymetry from this analysis. Those interested in either using the multibeam data or making further plots are referred to the digital data contained on the survey summary tape provided with this report, in the directory BATHY, where we provide digital contours, gridded data in GMT.grd format, and ASCII XYZ files of UTM Easting/Northings and depth in meters.

**Operational Notes**

Though this system is much more efficient than single-channel bathymetric mappers, it should be noted that it has a much smaller swath width than side-scan systems. Since its area of coverage is confined to a 90° angle below the ship, it covers relatively small areas, particularly

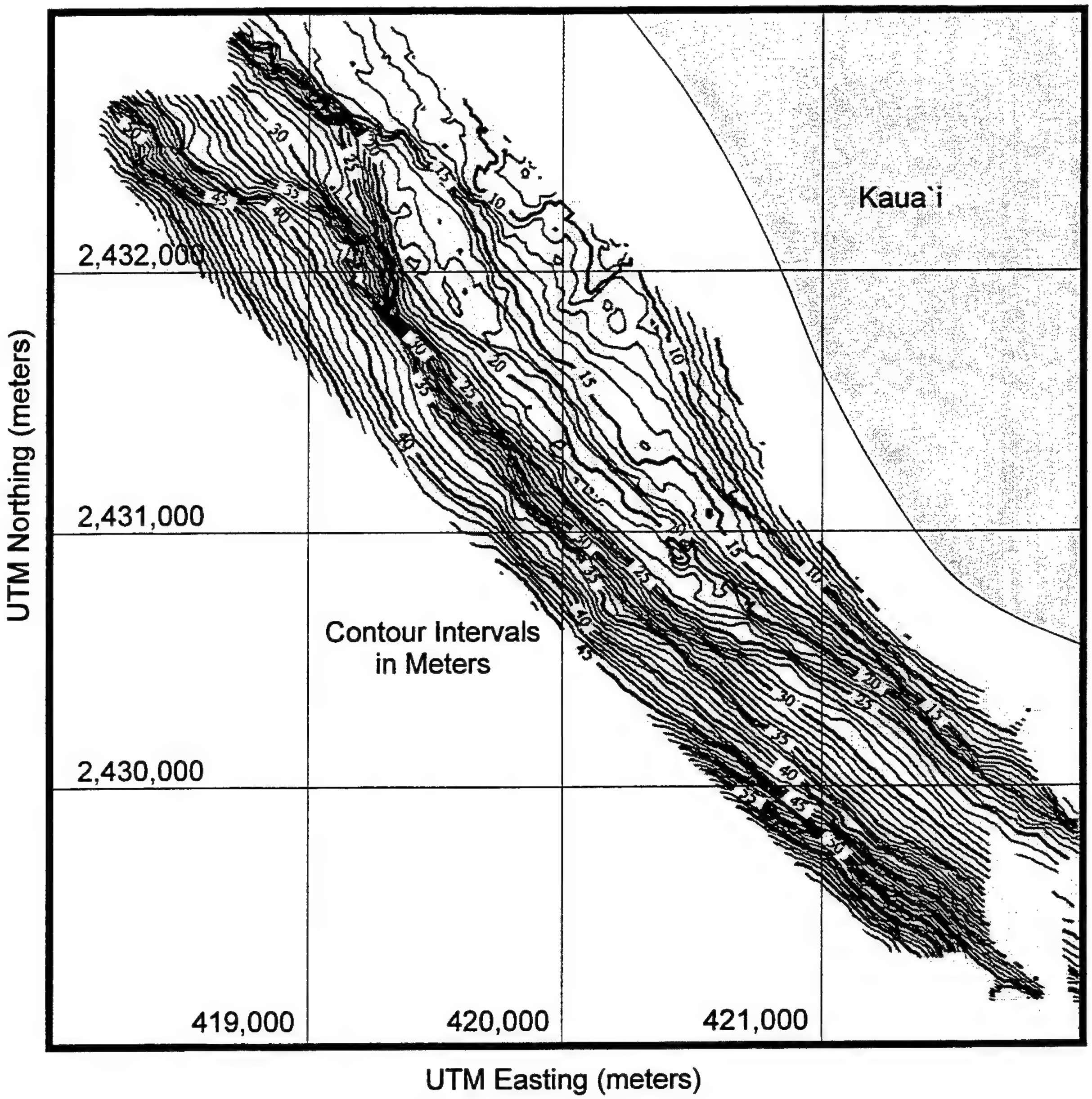



Figure 1. Test Range Bathymetry

in shallow water. It was not possible to retrieve saturation coverage in the test range, and bathymetric depths are inferred between swaths in the shallow half of the range. Two small areas of unconsolidated sediments were inferred from the records with low backscatter amplidutes. These two areas were used for the subsequent shallow-reflection profiling surveys.

## SIDE-SCAN SONAR SYSTEM

### System Description

This system consists of an EG&G® DF-1000 digital, dual frequency (100 and 500 kHz) towfish and digital conversion unit run by a newly developed topside processing software package hosted on a Sun® workstation computer. The system has been developed by OIC during the past two years. The side-scan system is commercially available from EdgeTech® and the topside processing software is available for workstation computers from OIC.

### Overall Assessment

Side-scan sonar does appear to be the most appropriate system for initial location of proud UXO prospects on the seabed. However, significant operational problems, discussed below, essentially prohibited a thorough examination of the capabilities of this system, though the system did produce apparently good data covering the entire test range. There is some question about the reliability of the particular hardware used, and future workers may get better results with other designs. Of the two data acquisition systems tested, the following conclusions are apparent:

1. The OIC workstation-based system has significantly better real-time observation capabilities and thus offers better opportunities for rapid target identification than the MMTC PC-based system.

2. The PC-based system is considerably more robust and easier to operate than the workstation system. The relative complexity and slow re-boot time of the workstation system (UNIX operating system vs. DOS) make it more difficult to transport and more time-consuming to implement.

Given the current rapid pace of developments in the simplification of workstations and the processing capacity of PC-based systems, it is likely that these conclusions will be moot in the near future.

The data analysis presented below suggests that, even with the limitations which existed in the survey, the system is capable of identifying about one third of the proud targets within range of the system. As would be expected, detection is easiest on flat, sandy surfaces and most difficult in areas with hard, irregular substrates. Surprisingly, there appears to be little correlation between the magnitude of the sonar return and the size of the targets, within the ranges explored in this study. No discrimination between UXO and metallic, non-UXO targets was achieved.

## Primary Data Analysis

While the data were being collected, likely targets (i.e. small targets with high back-scatter) were selected from the incoming data stream by the workstation operator, and 250 x 250 pixel samples about these selected targets were recorded in separate files. A total of 211 such selections were made.

Data collections efforts were severely impacted by several mechanical and electronic failures. In addition, replacement components supplied by the manufacturer were ill-tuned and not field adjustable, resulting in degraded data quality for the 500-KHz data. Electrical grounding problems and acoustic noise from external sources impacted the 100-KHz data as well for some portions of the data.

OIC provided real-time integration of sonar data and navigation and post-acquisition playback processing for target identification and location. Due to these noise sources, not all data were sufficiently noise-free for sub-meter target detection, but the 8 data lines, processed and included in Folio Fold-out Map 2, cover the majority of the survey area. The data files from each line were processed by OIC, and a list of target prospects, with associated sonar images, were provided to MMTC for further examination. Significant problems discovered in data processing are detailed below.

1. **Poor Dynamic Range/System Gains**. As mentioned above, the internal system time-varying-gain (TVG) pre-sets were ill-set by the manufacturer, and not field adjustable with the tools available to us at the time. While the data range of the 500 KHz exceeded (and saturates) above 10 bits, that of the 100 KHz data does not even reach a full 8 bit dynamic range (see Figure 2). This saturation of the 500 and low dynamic range of the 100 KHz data severely limited our ability to detect targets.

2. **Noise Corruption and Poor System Beam-pattern**. OIC applied adaptive beam-pattern correction to the data, but undoubtedly some loss in signal/noise resulted because of the poor initial beam pattern in the system. While significant image area has been recovered by reduction of beam-pattern artifacts, random shot-noise and "tiger-striping" due to grounding fault severely impacted the data. More than half the data collected were corrupted by such noise. While efforts to reduce these problems will continue after this report, it is clear that the proper remedy is better control over data collection.

3. **Navigation**. After filtering of attitude, navigation and gain corrections, each "line" of data was digitally mosaicked, allowing superposition of known target locations on geo-referenced imagery to aid in detection of acoustic targets in the full-resolution data visible simultaneously in the waterfall. While numerous targets were detected in this fashion, we were unable to provide more than a "target/no-target" response, due to absence of auxiliary classification information.

4. **Lack of Towfish Heading:** Early in the surveying, the heading indicator on the towfish stopped working. As discussed below, this exacerbated the problems already present in the location of the target prospects.

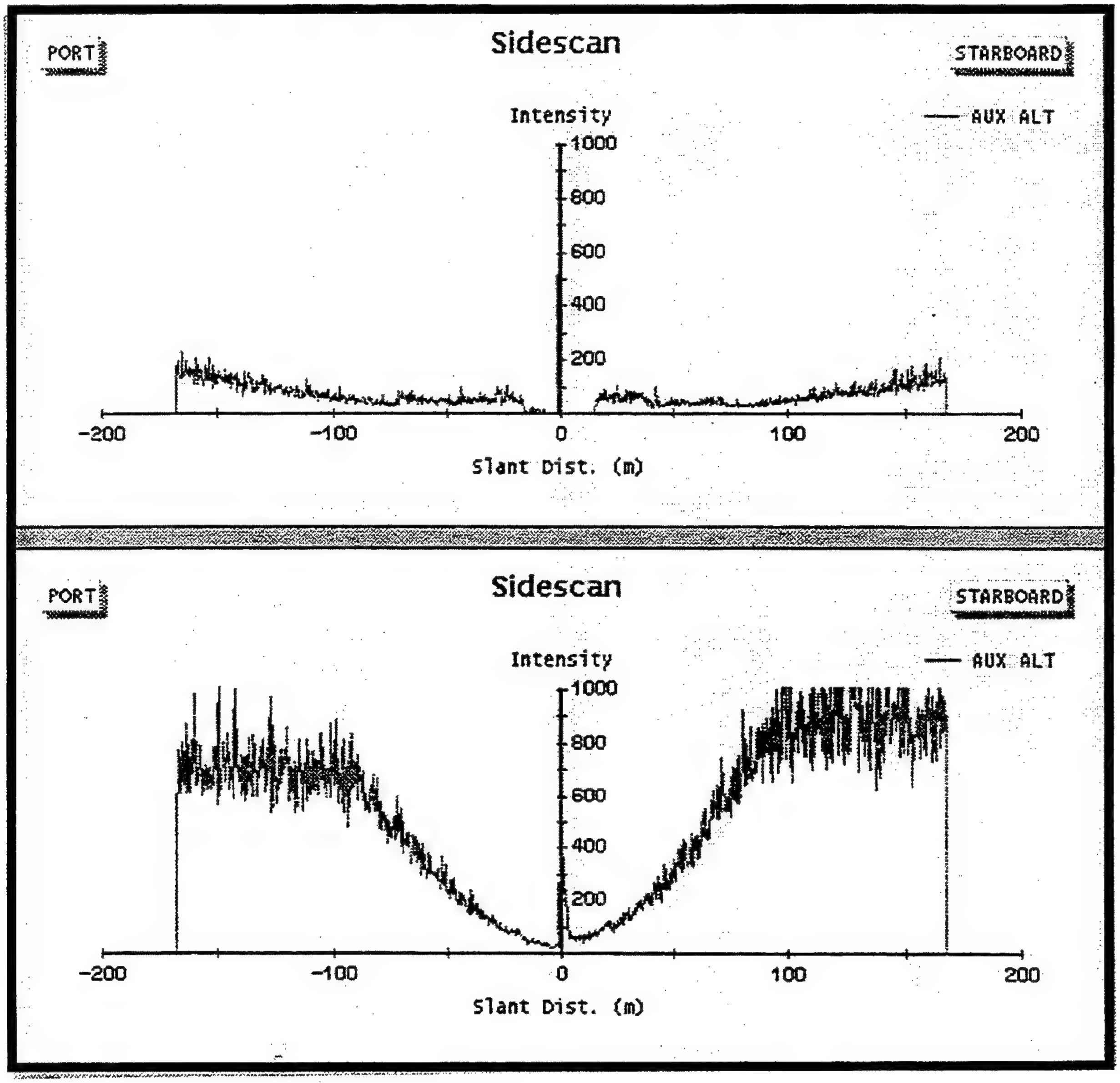



Figure 2. Screen Capture Showing Side-scan Signal Dynamic Range

Figure 3 shows the distribution of the side-scan sonar data, and the coverage of that data within the survey area. Nominal line spacing and range were 150 m, creating 100% overlap. A total of 6 survey lines were of sufficient quality for processing, including lines 4, 5, 6, 7, 9 and 10. The targets detected in each line or pair of lines are discussed below. Examination of overlapping swaths of sonar data in the side-scan sonar mosaic indicate that relative navigation is in good agreement track-to-track for lines 9, 7 and 6, with features matching to better than 10 meters (mosaic resolution is 0.5 meters). Lines 5 and 4, however, exhibit up to 50 meters of feature mismatch, indicating a break-down in navigation quality in deeper waters.

**Secondary Data Analysis**

In an attempt to address the primary objective of the project, efforts were made to resolve the clear discrepancies between the data collected by the side-scan system and the known locations of the proud targets. The following sections describe this effort. First, the assumptions and methodology are described, and then the results of the analysis are presented. Finally, the potential implications for using side-scan sonar to locate and classify UXO are discussed.

*Assumptions and Methodology*

Without some correction for the large errors made in navigation, it is not possible to perform direct comparisons between the known targets on the seabed and the resultant sonar images which are produced from them, since the mean distances between actual target positions are on the order of the position error. To provide such correction, the following assumptions are adopted:

1. The erroneous position assigned to at least one of the target prospects noted during each survey line lies relatively close (within 100 m) to the actual target position, and the actual target has the closest target location (of the known targets) to this erroneous position.

2. The error for each survey line is systematic and can at least be approximated by a single offset for the entire line. This assumption is justified if most of the navigation error is caused by wind and layback and currents. These offsets should be consistent during a single survey line, where speed and heading are maintained as constant as possible. Such offsets will move the towfish offline behind the survey vessel, leading to a lateral offset as well as a towfish heading error.

Based on these assumptions, the following algorithm was applied independently to each survey line to adjust the target prospect positions. All work was done on a desktop personal computer using the QBasic programming language.

1. The closest target for each prospect position is identified.

2. Using the position offsets from the larger (medium size and weight and larger targets) target-prospect pairs, the survey-line positions are sequentially adjusted for each offset.

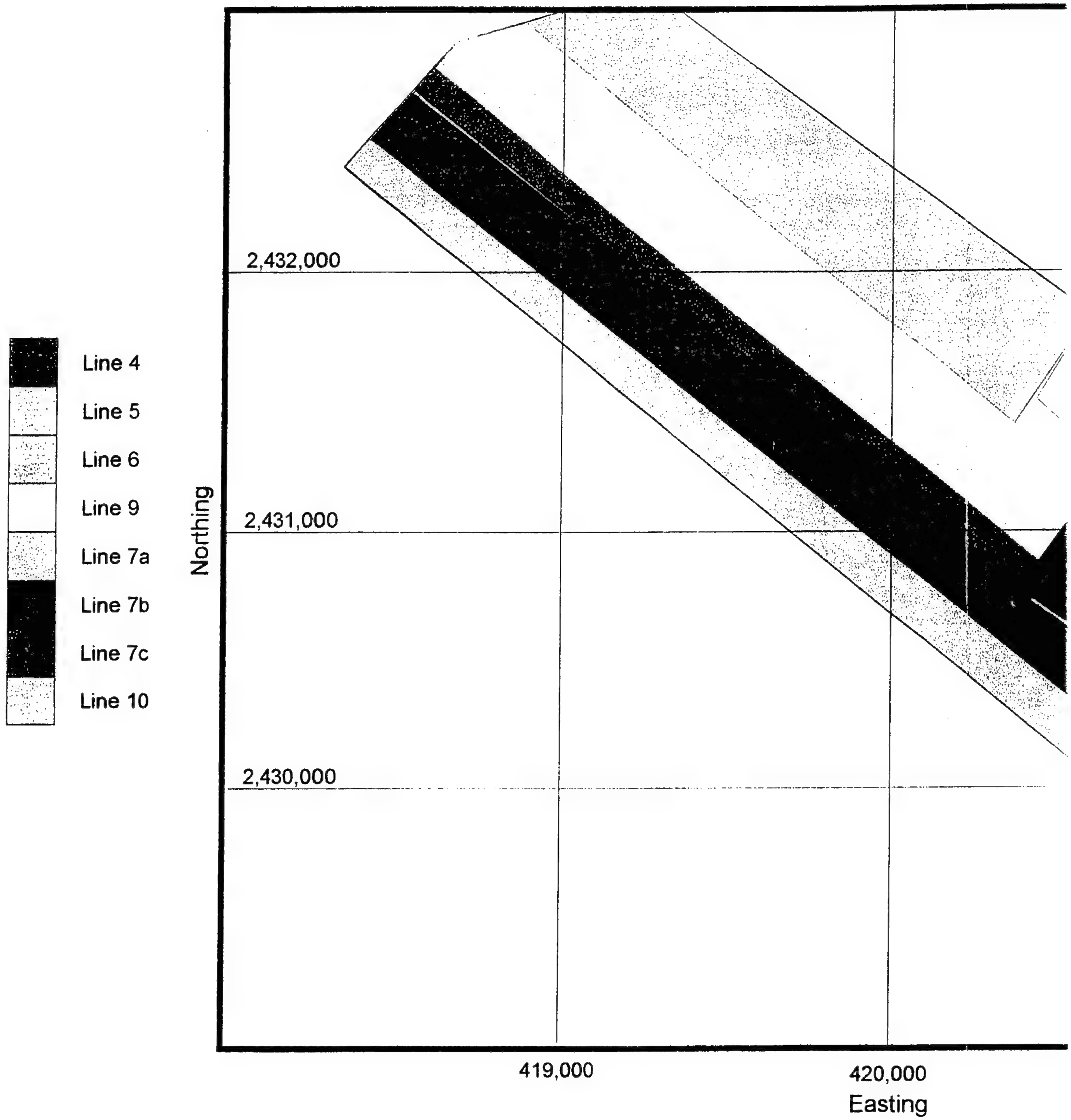
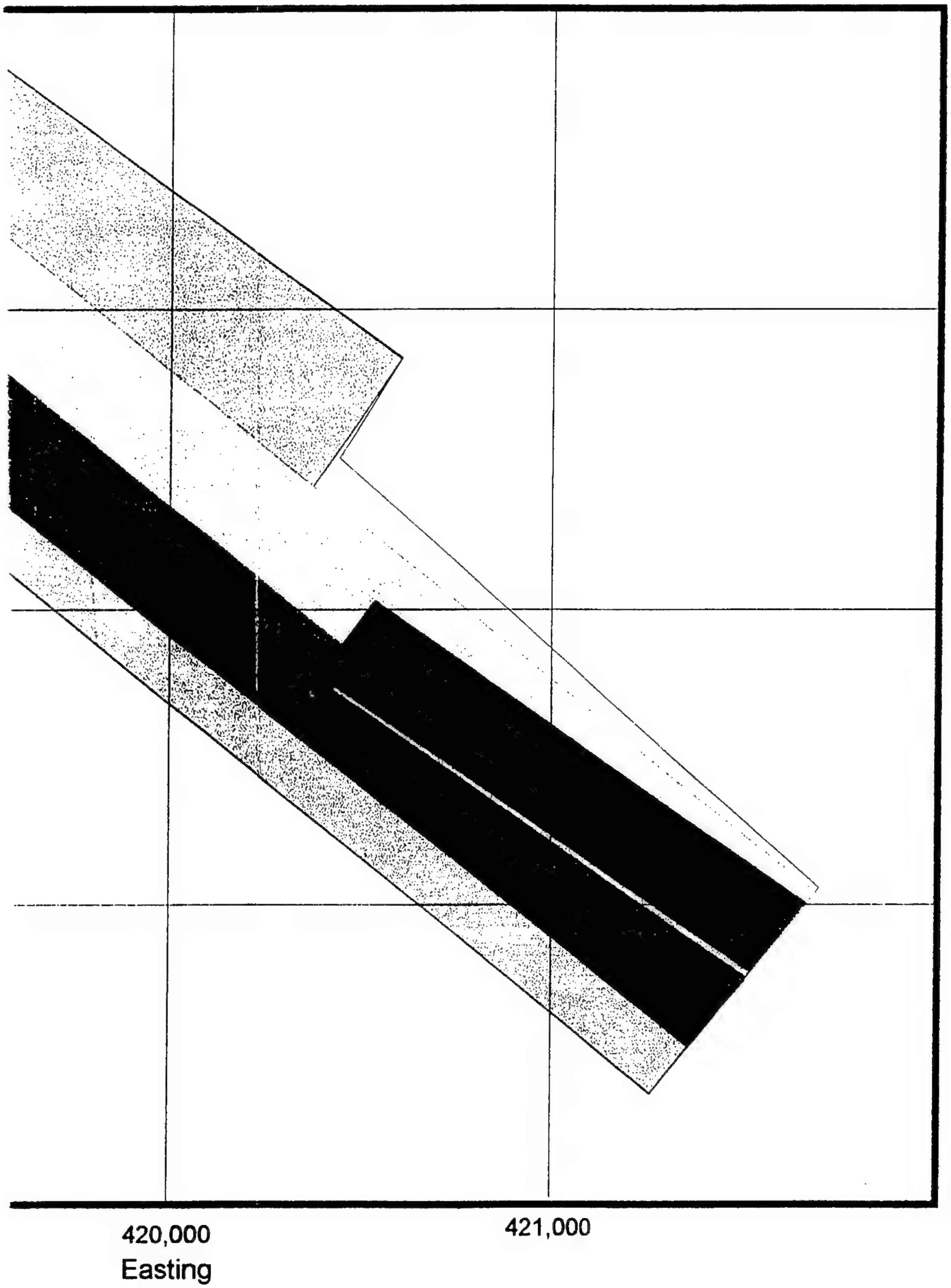



Figure 3. Approximate Distribution of Side-Scan Sonar Cove

(1)




ʖide-Scan Sonar Coverage

②

3. The offset resulting in the minimum sum of target-prospect distances is selected as the optimum adjustment of the survey line.

4. New positions are calculated for all prospects, and prospects which are less than 50 m from their associated targets are included as detected targets. Other prospects are deemed to be false positives.

Clearly, this adjustment must result in some improvement in correspondence between the prospects and targets, and such improvement by itself proves nothing. Thus another key part of this analysis is the identification of independent criteria to validate or refute the efficacy of the procedure. Three such criteria are examined here.

1. **Systematic Offsets Consistent With Ambient Conditions.** If the major navigation errors are due to current and wind sets or due to primary layback errors, then then the position offsets generated by this process should be physically meaningful within the context of the wind and tidal currents in the survey area or at least consistent during each survey line.

2. **Target Bias.** Presumably, targets with exposed angular surfaces are more likely to result in a significant sonar return than smooth ones. Random assignment of the targets with the prospects would produce the same frequency distribution of target size classes in the "detected" population as in the original target population. Real detection of targets should produce a distribution of target shapes which shows higher frequencies of the more angular classes than is present in the original population.

3. **Substrate Bias.** Targets on smooth, absorptive substrates such as sand are expected to be easier to detect than those on rough, hard substrates. Thus the distribution of detected targets should show a higher occurrence of targets on smooth, soft substrates than exists in the original target population.

*Analytical Results*

Table 1 presents the adjusted positions of the prospects and the identifications of the associated targets. Table 2 presents the summary data on the calculations of the offsets and the relevant tidal information for each run. Note that all but two of the runs indicate sets to the west of the side-scan towfish. This is consistent with the expected tidal currents (e.g. Gerritsen, 1978) and trade-wind activity during the surveys. Note also that all but one of the sets are less than 50 m, though the cut-off in the algorithm was 100 m. Improvements in the overall fit of the data to the actual target locations varies from 1% to 24%. The improvements are calculated using all the data, before the selection of targets less than 50 m from the associated prospect sonar returns.

In order to obtain some basis for error calculations related to detection rates, the data for each survey line were examined separately to estimate the variance to be expected in detection rate. Table 3 summarizes these data. The mean detection rate among the survey lines is 45.7%. This implies a coefficient of variation of 0.314.

**Table 1. Side-Scan Target Detection Prospects**

| Survey Line | Prospect ID | Adjusted Easting | Adjusted Northing | Target ID | Nav. Error |
|---|---|---|---|---|---|
| 4 | 54-01 | 420935.0 | 2430107.8 | D006 | 20.6 |
| 4 | 54-03 | 420923.0 | 2430109.0 | D006 | 9.6 |
| 4 | 54-04 | 420818.3 | 2430346.0 | D022 | 30.7 |
| 4 | 54-05 | 420682.9 | 2430467.0 | D026 | 42.9 |
| 4 | 54-06 | 420700.1 | 2430360.0 | D020 | 49.1 |
| 4 | 54-08 | 420435.2 | 2430592.3 | D035 | 25.4 |
| 4 | 54-11 | 420011.9 | 2431039.0 | D068 | 37.4 |
| 4 | 54-19 | 419232.1 | 2431833.0 | D126 | 27.7 |
| 4 | 54-20 | 418998.3 | 2432064.3 | D146 | 34.2 |
| 4 | 54-21 | 418830.2 | 2432225.8 | D158 | 0.0 |
| 4 | 54-22 | 418747.0 | 2432321.8 | D164 | 31.8 |
| 5 | 54-26 | 419065.9 | 2431972.8 | D138 | 15.9 |
| 5 | 54-29 | 419319.1 | 2431667.8 | D119 | 12.2 |
| 5 | 54-32 | 420045.3 | 2431098.8 | D068 | 35.2 |
| 5 | 54-34 | 420440.6 | 2430575.8 | D035 | 37c |
| 5 | 54-36 | 420516.2 | 2430402.0 | D025 | 28.8 |
| 5 | 54-37 | 420746.4 | 2430463.0 | D026 | 44.0 |
| 5 | 54-38 | 420746.7 | 2430344.5 | D020 | 0.0 |
| 5 | 54-42 | 421218.5 | 2429807c | C035 | 39.5 |
| 5 | 54-43 | 421252.3 | 2429791.0 | C023 | 47.4 |
| 6 | 69-00 | 420721.8 | 2430462.5 | D026 | 28.7 |
| 6 | 69-01 | 419886.1 | 2431518.8 | D105 | 48.3 |
| 6 | 69-09 | 419205.2 | 2432087.0 | D149 | 20.7 |
| 6 | 69-62 | 421408.5 | 2429913.5 | C021 | 39.3 |
| 6 | 69-64 | 421425.5 | 2429987.0 | C020 | 21.5 |
| 6 | 69-65 | 421373.9 | 2429932.3 | C021 | 0.0 |
| 6 | 69-66 | 421300.2 | 2430072.5 | C032 | 40.3 |
| 6 | 69-67 | 421261.6 | 2430206.5 | D013 | 27.7 |
| 6 | 69-68 | 421172.0 | 2430014.0 | C045 | 33.6 |
| 6 | 69-70 | 421041.9 | 2430083.0 | D004 | 26.4 |
| 6 | 69-74 | 420722.1 | 2430463.0 | D026 | 29.3 |
| 7a | 7A-00 | 421449.5 | 2429863.0 | C009 | 3.9 |
| 7a | 7A-03 | 421399.3 | 2430023.0 | C020 | 23.1 |
| 7a | 7A-04 | 421349.7 | 2429936.5 | C021 | 24.6 |
| 7a | 7A-05 | 421280.6 | 2429968.5 | C033 | 0.0 |
| 7a | 7A-07 | 421315.4 | 2430055.3 | C032 | 20.6 |
| 7a | 7a-10 | 421016.3 | 2430517c | C056 | 26.8 |
| 7a | 7a-11 | 420947.4 | 2430468.5 | D029 | 4.0 |
| 7a | 7a-13 | 420811.2 | 2430606.8 | D034 | 7.0 |
| 7a | 7a-15 | 420458.9 | 2430729.3 | D047 | 34.2 |
| 7b | 7B-00 | 421449.6 | 2429863.3 | C009 | 3.6 |

| Table 1. Page 2/3 | | | | | |
|---|---|---|---|---|---|
| Survey Line | Prospect ID | Adjusted Easting | Adjusted Northing | Target ID | Nav. Error |
| 7b | 7B-01 | 421355.2 | 2429932.0 | C021 | 18.7 |
| 7b | 7B-04 | 421475.7 | 2429957.5 | C008 | 31.1 |
| 7b | 7B-06 | 421280.6 | 2429968.5 | C033 | 0.0 |
| 7b | 7B-02 | 421399.5 | 2430023.5 | C020 | 23.4 |
| 7b | 7B-07 | 421315.1 | 2430054.8 | C032 | 20.9 |
| 7b | 7B-05 | 421483.3 | 2430081.5 | C019 | 7.4 |
| 7b | 7B-08 | 421354.2 | 2430147c | C031 | 36.1 |
| 7b | 7B-09 | 421081.5 | 2430169.3 | D010 | 6.1 |
| 7b | 7b-13 | 421014.5 | 2430518.5 | C056 | 29.0 |
| 7b | 7b-15 | 420845.2 | 2430594.5 | D034 | 30.8 |
| 7c | 7C-01 | 420678.9 | 2430892.3 | D059 | 46.8 |
| 7c | 7C-02 | 420464.3 | 2430741.5 | D047 | 32.9 |
| 7c | 7C-03 | 420502.9 | 2430756.5 | D048 | 19.8 |
| 7c | 7C-05 | 420373.9 | 2430866.0 | D057 | 42.1 |
| 7c | 7C-06 | 420504.7 | 2430960.8 | D060 | 41.4 |
| 7c | 7c-17 | 419741.9 | 2431549.5 | D107 | 19.6 |
| 7c | 7c-19 | 419375.1 | 2431952.0 | D134 | 39.2 |
| 7c | 7c-20 | 419314.5 | 2432174.0 | D155 | 16.0 |
| 7c | 7c-21 | 419228.1 | 2432108.8 | D149 | 30.0 |
| 7c | 7c-22 | 419198.2 | 2432106.5 | D149 | 0.0 |
| 9 | 69-21 | 419189.5 | 2432350.0 | D172 | 39.3 |
| 9 | 69-23 | 419378.6 | 2432371.5 | D171 | 22.1 |
| 9 | 69-25 | 419457.7 | 2432244.5 | D160 | 15.9 |
| 9 | 69-29 | 419601.2 | 2432005.5 | D141 | 20.4 |
| 9 | 69-34 | 419973.1 | 2431713.5 | D122 | 44.8 |
| 9 | 69-35 | 420121.1 | 2431573.8 | D109 | 24.0 |
| 9 | 69-36 | 420171.5 | 2431591.8 | D109 | 47.7 |
| 9 | 69-38 | 420253.1 | 2431500.0 | D106 | 29.2 |
| 9 | 69-40 | 420411.5 | 2431319.5 | D092 | 34.5 |
| 9 | 69-46 | 420943.2 | 2430678.3 | D039 | 22.7 |
| 9 | 69-48 | 421164.5 | 2430501.0 | C053 | 14.0 |
| 9 | 69-50 | 421055.6 | 2430506.0 | C056 | 23.5 |
| 9 | 69-51 | 421100.8 | 2430576.3 | C055 | 9.8 |
| 9 | 69-52 | 421191.2 | 2430385.8 | C052 | 29.9 |
| 9 | 69-53 | 421238.7 | 2430451.5 | C051 | 19.4 |
| 9 | 69-54 | 421252.0 | 2430304.5 | C050 | 6.7 |
| 9 | 69-55 | 421320.5 | 2430350.5 | C049 | 20.3 |
| 9 | 69-57 | 421406.5 | 2430355.0 | C041 | 7b |
| 9 | 69-59 | 421381.7 | 2430154.5 | C031 | 13.6 |
| 9 | 69-60 | 421610.0 | 2430122.3 | C006 | 4.5 |
| 9 | 69-61 | 421560.4 | 2430028.8 | C007 | 0.0 |
| 9 | 69-63 | 421370.4 | 2429806.0 | C010 | 38.3 |

| Table 1. Page 3/3 | | | | | |
|---|---|---|---|---|---|
| Survey Line | Prospect ID | Adjusted Easting | Adjusted Northing | Target ID | Nav. Error |
| 9 | 69-69 | 421130.0 | 2430191.3 | D010 | 47b |
| 10 | 10-02 | 419844.7 | 2431908.3 | D131 | 12.6 |
| 10 | 10-03 | 419755.4 | 2432030.0 | D143 | 47.8 |
| 10 | 10-08 | 419228.5 | 2432522.5 | D180 | 18.8 |
| 10 | 10-09 | 419181.4 | 2432684.5 | D189 | 39.6 |
| 10 | 10-14 | 419767.9 | 2432433 | D177 | 31.8 |
| 10 | 10-16 | 419878.4 | 2432272 | D163 | 0 |
| 10 | 10-19 | 420204.8 | 2431957.5 | D137 | 23 |
| 10 | 10-21 | 420382.6 | 2431948.8 | D139 | 32.5 |

**Table 2. Effects of Adjusting Survey Lines and Relevant Tidal Data**

| Survey Line | 4 | 5 | 6 | 7a | 7b | 7c | 9 | 10 |
|---|---|---|---|---|---|---|---|---|
| %Gain* | 5 | 22 | 1 | 19 | 24 | 3 | 2 | 3 |
| dx(meters) | -33.0 | 32.1 | 9.8 | 6.5 | 6.6 | 11.1 | -8.4 | 13.6 |
| dy(meters) | 4.0 | 60.8 | 2.8 | -25.8 | -25.5 | -13.0 | 7.5 | -7.5 |
| Start Time | 14:08 | 13:18 | 13:05 | | 09:24 | | 14:14 | 09:24 |
| Finish | 14:48 | 13:57 | 13:58 | | 10:19 | | 14:46 | 10:19 |
| High Tide | 09:50 | 09:50 | 08:40 | | 08:40 | | 08:40 | 8:40 |
| Low Tide | 17:30 | 17:30 | 15:00 | | 15:00 | | 15:00 | 15:00 |
| Tidal Stage | ebb | ebb | ebb | | ebb | | final ebb | high stand |
| Line Direction | S | N | S | | N | | N | N |

*Percent decrease in mean distance between prospects and associated targets after adjustment

**Table 3. Target Detection Rates**

| Survey Line | Available Targets* | Number Detected | Percent Detected | Area Covered ($km^2$) |
|---|---|---|---|---|
| 4 | 36 | 11 | 31 | 0.635 |
| 5 | 27 | 9 | 33 | 0.682 |
| 6 | 39 | 11 | 28 | 0.761 |
| 7a | 19 | 9 | 47 | 0.268 |
| 7b | 15 | 11 | 73 | 0.191 |
| 7c | 23 | 10 | 43 | 0.545 |
| 9 | 39 | 23 | 59 | 0.781 |
| 10 | 16 | 8 | 50 | 0.322 |

*All proud targets within 100 m horizontally off the vessel track

**Table 4. False Positive Side-Scan Detection Prospects**

| Survey Line | Number of Prospects | Number With Associated Targets | Percent False Positives |
|---|---|---|---|
| 4 | 21 | 11 | 48 |
| 5 | 20 | 9 | 55 |
| 6 | 27 | 11 | 59 |
| 7a | 15 | 9 | 40 |
| 7b | 16 | 11 | 31 |
| 7c | 25 | 10 | 60 |
| 9 | 40 | 23 | 43 |
| 10 | 17 | 8 | 53 |

To investigate the role that the substrate may have in influencing the resultant detection rate, we use the substrate types noted for each target by NFESC. We summarize these as follows:

1. Smooth sand

2. Sand with ripples

3. Sand with sand waves

4. Sand with rubble (with or without limu, soft algae)

5. Hard, flat rock

6. Irregular rock and a cave

Table 5 summarizes the detection rates for these various categories. Duplicate detections, which occured commonly because of the extensive overlap between runs, are not counted in this analysis. As can be seen in this table, there does appear to be some difference in detection rate among the substrate types, particularly if the first three and last three categories are lumped into two larger groups.

**Table 5. Effect of Substrate on Target Detection**

| Substrate | Available Targets | Targets Detected | Percent Detected | Estimated Error (%) |
|---|---|---|---|---|
| 1 | 43 | 14 | 33 | 7 |
| 2 | 52 | 26 | 50 | 8 |
| 3 | 6 | 2 | 33 | 16 |
| 4 | 72 | 23 | 32 | 5 |
| 5 | 3 | 2 | 67 | 77 |
| 6 | 3 | 1 | 33 | 51 |
| 1,2&3 | 101 | 42 | 42 | 6 |
| 4,5&6 | 78 | 26 | 33 | 5 |

To investigate the potential effect of target types on the detection rate, we initially grouped the targets by size and weight, similar to the categories adopted by NFESC in their description of the targets. This exercise does not show any increase in the percentage of larger targets in the set of detected prospects, and the Pearson correlation coefficient calculated between size class and prospect detection strength, as defined in our preliminary report to NFESC, is 0.06. After some discussion with various colleagues on this matter, we formulated another set of classes, based on shape rather than size. An acoustic echo should be stronger from exposed, angular surfaces than
from smooth round surfaces. On this basis we organized the targets into four classes: Class 1, which includes round cylindrical shapes with relatively low elevation when lying on their sides, Class 2, which includes slightly higher profiles and some flat surfaces exposed, such as oil drums, Class 3, with sharp angular edges but horizontal, low profiles, such as ammo boxes, and Class 4, with significant exposed, angular surfaces at relatively high profiles, such as bombs and projectiles with fins. The classes for the detected targets are shown in Table 6. The correlation between these categories and the sonar reflection strengths (termed "prospect return class" in the table) is almost as bad as the size classes ($r=0.07$). The apparent bias of the detected targets for the higher classes, presented in Table 7, is intriguing, though not compelling.

Table 6. Shape Classifications of Detected Targets

| Target ID | Target Description | Target Shape Class | Num. Prospect Hits | Prospect Return Class |
|---|---|---|---|---|
| C006 | MK81 | 1 | 1 | 2.0 |
| C007 | MK81 | 1 | 1 | 3.0 |
| C008 | FRAG | 1 | 1 | 2.0 |
| C009 | MK82 | 1 | 2 | 2.0 |
| C010 | MK81 | 1 | 1 | 3.0 |
| C019 | 3MK106 | 4 | 1 | 3.0 |
| C020 | MK76 | 4 | 3 | 2.7 |
| C021 | MK76 | 4 | 4 | 2.0 |
| C023 | MK76 | 4 | 1 | 2.0 |
| C031 | PROJ554 | 1 | 2 | 2.5 |
| C032 | PROJ538 | 1 | 3 | 2.3 |
| C033 | PROJ538 | 1 | 2 | 2.0 |
| C035 | PROJ554 | 1 | 1 | 2.0 |
| C041 | ROCK5 | 1 | 1 | 3.0 |
| C045 | ROCK5 | 1 | 1 | 3.0 |
| C049 | ROCK275 | 4 | 1 | 2.0 |
| C050 | CART20M | 3 | 1 | 3.0 |
| C051 | CART554 | 3 | 1 | 3.0 |
| C052 | CASE40M | 3 | 1 | 3.0 |
| C053 | MKI06 | 4 | 1 | 3.0 |
| C055 | ROCK7 | 4 | 1 | 3.0 |
| C056 | 2ROCK275 | 4 | 3 | 1.3 |
| D004 | LDRUM N/A | 2 | 1 | 3.0 |
| D006 | MDRUM N/A | 2 | 2 | 1.0 |
| D010 | AM_BOX N/A | 3 | 2 | 2.0 |
| D013 | MK76 Practice Bomb | 4 | 1 | 3.0 |
| D020 | 5APIPE N/A | 1 | 2 | 2.5 |
| D022 | 3SPIPE N/A | 1 | 1 | 2.0 |
| D025 | CART20M Other | 3 | 1 | 1.0 |
| D026 | AM_BOX N/A | 3 | 4 | 2.0 |
| D029 | ROCK5 RocketWhd | 1 | 1 | 2.0 |
| D034 | ROCK275RocketWhd | 4 | 2 | 2.0 |
| D035 | ROCK7 RocketWhd | 4 | 2 | 2.0 |
| D039 | MK106 PracBomb | 4 | 1 | 3.0 |
| D047 | 2PROJ538Projectile | 1 | 2 | 2.0 |
| D048 | MK106 PracBomb | 4 | 1 | 3.0 |
| D057 | ROCK5 RocketWhd | 1 | 1 | 3.0 |
| D059 | CART20M Other | 3 | 1 | 2.0 |
| D060 | MK76 Practice Bomb | 4 | 1 | 3.0 |
| D068 | PROJ554Projectile | 1 | 2 | 2.0 |

| Table 6. Page 2/2 | | | | |
|---|---|---|---|---|
| Target ID | Target Description | Target Shape Class | Num. Prospect Hits | Prospect Return Class |
| D092 | CART762 Other | 3 | 1 | 1.0 |
| D105 | LCHAIN N/A | 4 | 1 | 2.0 |
| D106 | CART554 Other | 3 | 1 | 2.0 |
| D107 | MK106 PracBomb | 4 | 1 | 3.0 |
| D109 | ROCK7 RocketWhd | 4 | 2 | 2.5 |
| D119 | ROCK275RocketWhd | 4 | 1 | 2.0 |
| D122 | 2MK76 PracBomb | 4 | 1 | 3.0 |
| D126 | MK76 Practice Bomb | 4 | 1 | 2.0 |
| D131 | CASE40M Other | 3 | 1 | 3.0 |
| D134 | ROCK7 RocketWhd | 4 | 1 | 3.0 |
| D137 | 2ROCK5 RocketWhd | 1 | 1 | 3.0 |
| D138 | ROCK5 RocketWhd | 1 | 1 | 2.0 |
| D139 | 4SPIPE N/A | 1 | 1 | 3.0 |
| D141 | MK82 Large Bomb | 1 | 1 | 2.0 |
| D143 | ROCK275RocketWhd | 4 | 1 | 3.0 |
| D146 | ROCK7 RocketWhd | 4 | 1 | 2.0 |
| D149 | 3MK106 PracBomb | 4 | 3 | 2.3 |
| D155 | MK106 PracBomb | 4 | 1 | 3.0 |
| D158 | MK81 Large Bomb | 1 | 1 | 3.0 |
| D160 | MK81 Large Bomb | 1 | 1 | 2.0 |
| D163 | MK76 Practice Bomb | 4 | 1 | 3.0 |
| D164 | 4SPIPE N/A | 1 | 1 | 2.0 |
| D171 | ROCK275RocketWhd | 4 | 1 | 2.0 |
| D172 | AM_BOX N/A | 3 | 1 | 2.0 |
| D177 | ROCK275RocketWhd | 4 | 1 | 3.0 |
| D180 | PROJ554Projectile | 1 | 1 | 2.0 |
| D189 | ROCK275RocketWhd | 4 | 1 | 1.0 |

**Table 7. Differences in Target Detection and Target Shapes**

| Shape Class | Available Targets | Number Detected | Percent Detected | Estimated Error |
|---|---|---|---|---|
| 1 | 71 | 25 | 35 | 6 |
| 2 | 7 | 2 | 29 | 14 |
| 3 | 29 | 11 | 38 | 9 |
| 4 | 72 | 29 | 40 | 6 |
| 1&2 | 78 | 27 | 35 | 3 |
| 3&4 | 101 | 40 | 40 | 3 |

*Potential Implications for UXO Location and Classification*

As discussed above and in the Observational Notes below, the system used in this demonstration, because of navigational and other constraints, was by no means optimized for the job. However, in spite of these problems, the data do suggest that the technique in general has significant potential. The adjustment of survey line locations was in general consistent with a set of the towfish by wind and tidal currents, but did not result in dramatic improvement of the correspondence between the prospect and target positions. Adequate navigation for this purpose must have better control over the relative towfish position with respect to the survey vessel than was possible in this survey. Overall, the system appears to be able to detect approximately 40% of the targets on smooth, sandy areas, and much lower percentages of the targets in hard, irregular areas. There is an apparent false-positive detection rate of about 50%.

The statistics indicate marginal discrimination between the detection rates for different target shapes, and no distinction by target size. The survey data show consistency of the trends observed in the substrate and target bias estimates with expectations based on theoretical considerations, though the magnitudes of these trends are statistically marginal.

We suspect that the detection rates provided here are a good first approximation, and that much improvement is possible with respect to location precision, reduction of false positives, and shape discrimination. We believe it unlikely that the tool by itself will be capable of discerning UXO from non-UXO objects. Based on the complete lack of correlation noted between the prospect return signal strength and the actual target size, it is probable that other tools will be necessary complements to constitute an effective search technology.

**Operational Notes**

1. Operator errors (improper sealing of the towfish electronics) led to significant damage to the DF-1000 towfish. MMTC had tried to obtain a complete set of spares for the system, but they were unavailable from the manufacturer more than four months prior to the operation. We did manage to get a working system by borrowing the manufacturer's only functioning lab-test system and did complete the required surveys, but only at the end of the survey period. The lack of accurate navigation for the towfish, as described above, exacerbated the problem and has made simple interpretation of the records impossible.

2. Time-varying gain (TVG) is set by processors within the towfish which cannot be adjusted in the field. The unit provided by the manufacturer had a TVG for the 500 kHz signal which was misadjusted so that this data channel was clipped severely; only the near-field (<20 m lateral on the seabed) data are usable. This is a significant design problem for the DF-1000. The TVG should be adjustable in the field.

3. The DF-1000 is extremely sensitive to the properties of the signal cable, and accidents due to unexpected stress on the wire, mishandling, or other incidents leading to shorts or an open circuit can easily do major damage to the towfish electronics. Though this was not a factor in these operations, it is important to note in the evaluation of the system.

## AAHIS SYSTEM

### System Description

Because this system is not commercially available except from SETS Technology, Inc. it is described in somewhat more detail than the other, more conventional systems. AAHIS, the Advanced Airborne Hyperspectral Imaging System, has been developed by SETS Technology, Inc. SETS Technology, Inc. has developed a flight-tested, visible/near-infrared (432 nm to 830 nm) hyperspectral imaging system, optimized for use in maritime and near-shore applications. AAHIS is the technique of imaging a scene in many (tens or hundreds) of color bands, so that a complete spectrum is recorded at each spatial location in the image. Hyperspectral imaging (HSI) is distinguished from multispectral imaging by the number of spectral bands recorded (multi-spectral imagers typically record no more than a dozen spectral bands); by the narrowness of each hyperspectral band (typically 10 nm wide or less); and by the contiguous nature of the hyperspectral data. Hyperspectral imaging is distinguished from point spectrometry by the collection of spectral data sets for complete images, instead of just one point at a time.

*System Concept*

The AAHIS sensor is a "pushbroom" type imager which builds the image line-by-line. The sensor's primary optic images the scene onto the entrance slit of the spectrometer, so that only light from a single narrow image line (i.e., the pushbroom), oriented perpendicular to the direction of motion of the sensor, is allowed to pass into the spectrometer. Inside the spectrometer, this polychromatic line image is simultaneously dispersed into a two-dimensional spectrum and re-imaged onto the focal plane array. As the aircraft moves forward over the scene, the image of the slit scans the terrain below and the strip image is built up line-by-line, producing a hyperspectral "data cube" consisting of a stack of up to 288 monochromatic images. Spectral information is collected simultaneously in each of 288 separate bands of approximately 1.4 nm/band. In order to match spectrometer aberration and reduce data rate, the spectral dimension is nominally binned on the chip by 4, giving a spectral bandwidth of 5.5 nm.

Spatial resolution is determined by the sensor's instantaneous field of view (IFOV), by the spectrometer aberration, and by the frame L rate/ground speed of the aircraft. At an altitude of 1 km, with a frame rate of 40 frames per second and a ground speed of 80 knots (typical values), the ground sample distance (GSD) is approximately 1 m, which corresponds to the angular width of two pixels on the focal plane array. Therefore, to match the same GSD across-track as along-track, the chip is nominally binned by two in the spatial direction. This yields 192 spatially resolved channels. At this frame rate and for the 2x4 on-chip binning, the data is being recorded at 1.1 MB/sec. This is well within the data system recording capability (i.e., SCSI II interface capability).

*Sensor Components*

The AAHIS sensor (see the block diagram below) consists of the following: the imaging spectrometer (including the primary optics, or "foreoptics"); the spectrometer focal plane array

and controller; a scene monitor camera with video monitor and SVHS videotape recorder; a timebase generator; a computer with hard disk and 5 GB tape drive; the spectrometer vibration isolation mount and rack structure to mount the above items in the aircraft cabin (mounted to the seat rails); and an AC inverter power supply.

The low aberration, high throughput, and wide-field performance of the AAHIS imaging spectrometer are the key elements that enable the level of demonstrated capabilities. Light enters the f/4, 50 mm focal length foreoptic and is imaged onto the slit of the spectrometer. Light through the slit passes through a two-element field flattening lens onto a single plane reflection grating. A second reflective element images (with magnification less than one) onto the spectrometer focal plane array (FPA). The FPA is a high speed frame-transfer CCD with 385x576 pixels cooled to less than -20 °C. This FPA incorporates a UV-enhanced coating which increases the silicon CCD quantum efficiency for wavelengths shorter than 450 nm. The FPA uses "frame transfer" readout, wherein photocharge in the active, exposed central half of the FPA is quickly shifted under a mask to be read off the chip while photocharge from the next frame is integrated in the active half [i.e., the active portion of the FPA is 385 (spatial) x 288 (spectral)]. This reduces the read rate of the chip (i.e., electronic noise) and minimizes spectral/spatial "smear" during the readout of the FPA (i.e., 1.2 ms frame transfer compared to an approximate 25 ms integration time). Photocharge from each pixel is transferred to the gate of an FET, where it is converted into a voltage signal. This analog voltage signal is then converted into a 12-bit number by an analog-to-digital converter. Two 8-bit bytes are used to store the value of each pixel to prevent distortion of the upper or lower bit.

*Computer Control*

The AAHIS sensor is controlled by a Macintosh Quadra 800 computer, equipped with 72 MB of RAM. During data collects, image data are written directly to this RAM, so that approximately 2400 frames (60 seconds of data at 40 frames per second) may be collected in an uninterrupted sequence before data must be transferred to a disk file on the Quadra's 1.2 GB internal hard drive (this takes approximately 10 seconds). Raw data may be downloaded to the 5.0 GB Exabyte tape drive between aircraft data runs.

A standard color CCD "spotter" camera supplies a video signal to a small monitor allowing the operator to view, in real time, the same ground scene the sensor is seeing. The scene is also ~captured by an SVHS videocassette recorder. A timebase is recorded directly onto the SVHS tape by a time code generator.

The spectrometer is cradled in a welded, black anodized aluminum frame on four vibration isolation mounts. The electronics (computer, camera controller, tape drive, time code generator and videocassette recorder) are mounted in a separate anodized, welded aluminum frame. Both frames are locked to the aircraft's seat rails. This permits rapid installation of the system in the aircraft. The sensor and scene monitor camera, having been precisely boresighted, look down through a windowless hole in the aircraft floor.

*Image Processing*

Processing is accomplished with HIPS™ SETS Technology's proprietary Hyperspectral Image Processing System. A Sun/UNIX workstation-based package, HIPS is a full-featured spectral image processing system with unique capabilities for processing hyperspectral data sets. HIPS is now being ported to the Maui High Performance Computing Center (MHPCC). At the termination of a data gathering flight, a tape cartridge containing raw HSI data is produced, ready for flat and dark field corrections, HSI analysis, display and printing. In addition, an SVHS videotape of the spotter camera's record of the ground track is produced, allowing the data analyst to correlate the "normal" view of the scene with the hyperspectral imagery.

**Overall Assessment**

Based on discussions with SETS Technology personnel it is probable that this system in its present configuration is not effective in location and classification of most of the targets. As discussed below, operational problems do limit somewhat the confidence of this assessment and modifications to the system could have significant impacts on the system's effectiveness for this purpose.

**Data Analysis**

SETS Technology, Inc. collected ~5GB of raw data, calibrated and converted it into HIPS data file format for analysis. Intensive processing using various techniques has not, to date, revealed any obvious underwater targets. Sub-pixel beach targets were easily identified. All targets were subpixel in size which is the reason we feel we were unable to identify the underwater targets. Ground resolution varied according to aircraft altitude.

SETS Technology, Inc. developed a GIS system in ArcView to display the location of the calibration area ordnance along with the aircraft overflight data based on the Flight Navigation System (FNS) operated with AAHIS. This GIS was critical in determining, with any degree of accuracy, the known location of targets which allowed us to constrain our data processing efforts on such a large amount of total data to specific areas. We chose to concentrate on data from a few overpasses on 6 August, during which there were favorable cloud conditions and on data from shallow water depths ( < 15 m). Figure 4 shows prints from ArcView indicating the flight paths over the calibration area for all of the flights on 6 August. Figure 5 shows prints from just flight 12 and 13.

Figures 6 and 7 show passes 1-30 for 6 August. The presence of clouds on 19-30 is clearly observable. We therefore processed the data for passes 12 & 13 for better cloud conditions, but also extensively processed pass 21 & 22. Figures 8 and 9 show spotter camera video data, RGB composite data, band 5 (blue), binned blue - binned red data, binned green - binned red data, and a ratio of the binned blue - red to binned green - red data for both scene 12 and 13. The effect of this type of processing was to subtract out the surface of the water to show more of just the underlying substrate (sea-bottom) conditions.

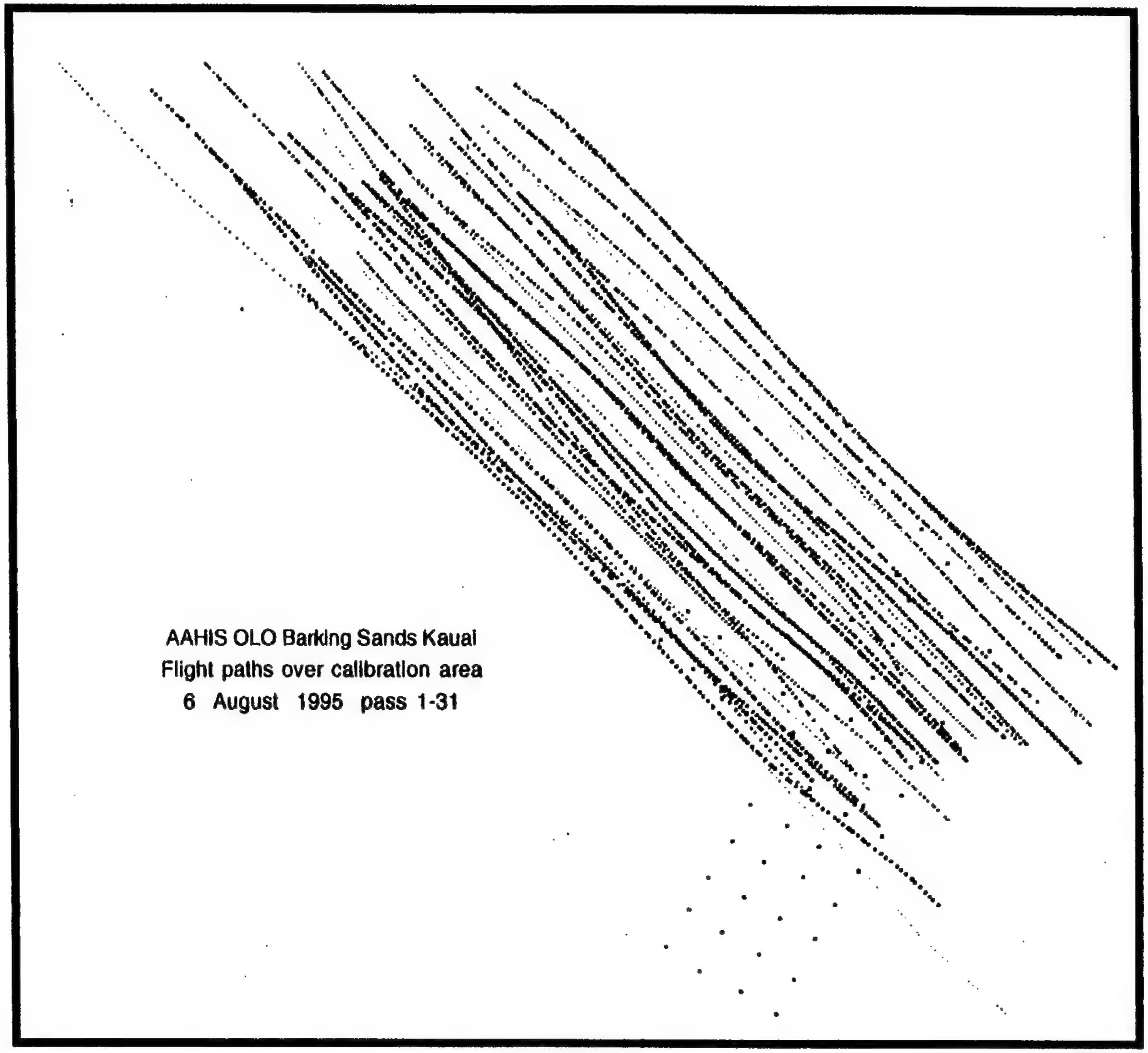



Figure 4. AAHIS Flight Paths over Calibration Area, 6 August, 1995

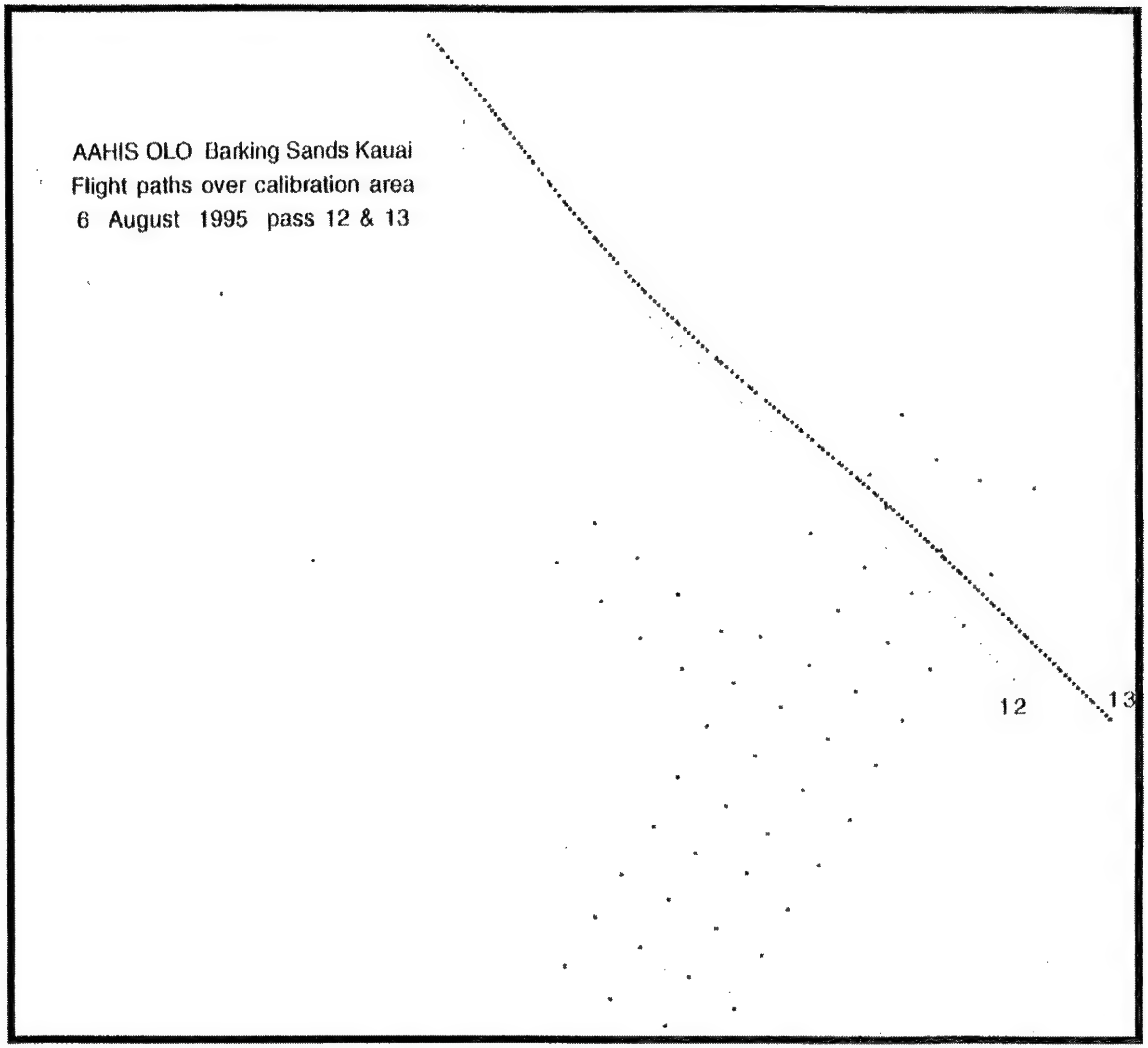



Figure 5. AAHIS Flight Paths 12 and 13, 6 August, 1995

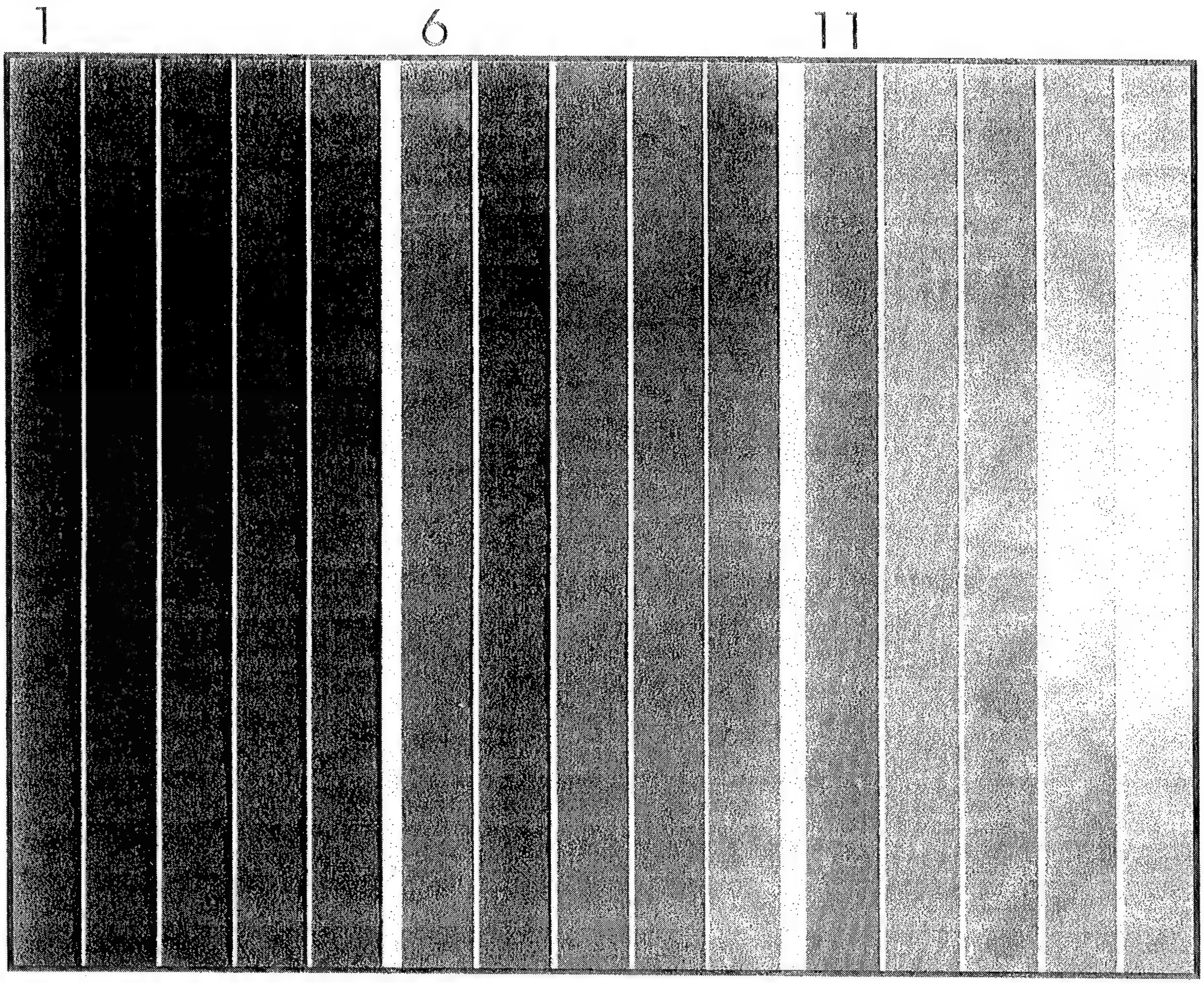



Figure 6. AAHIS Passes Over Test Range, 6 August, 1995 (1-15)

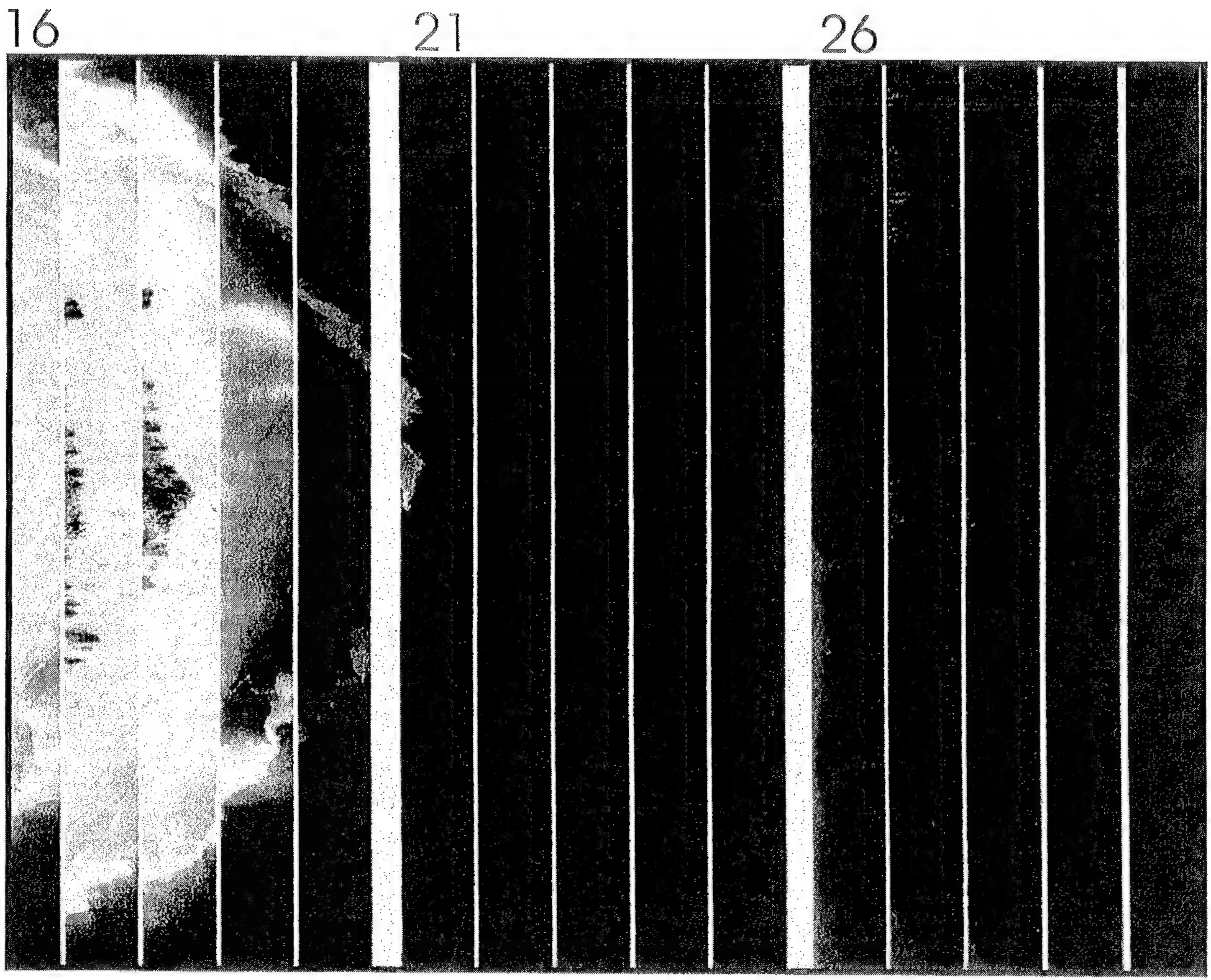



Figure 7. AAHIS Passes Over Test Range, 6 August, 1995 (16-30)

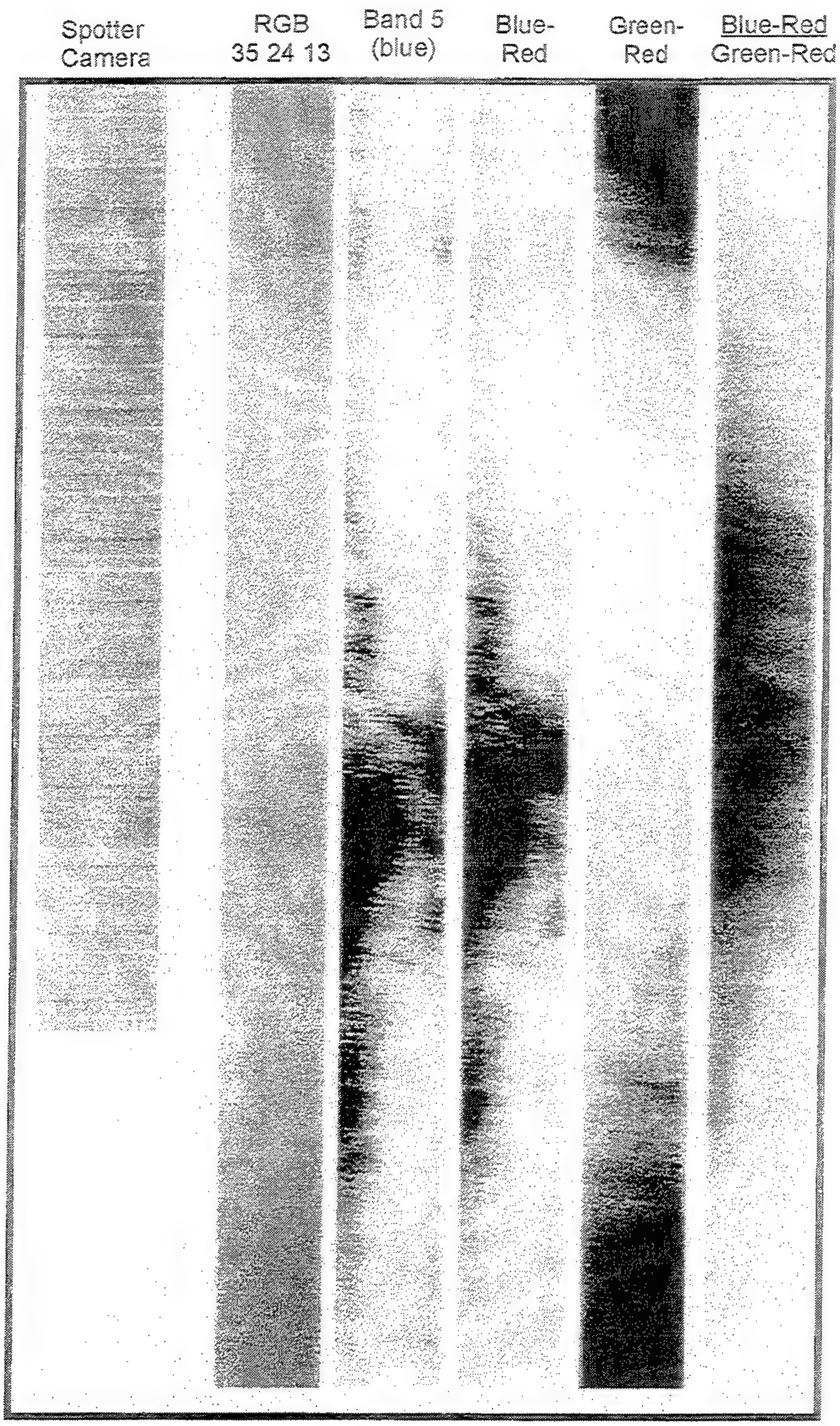



Figure 8. AAHIS Pass 12, 6 August, 1995 Color Isolation Analysis

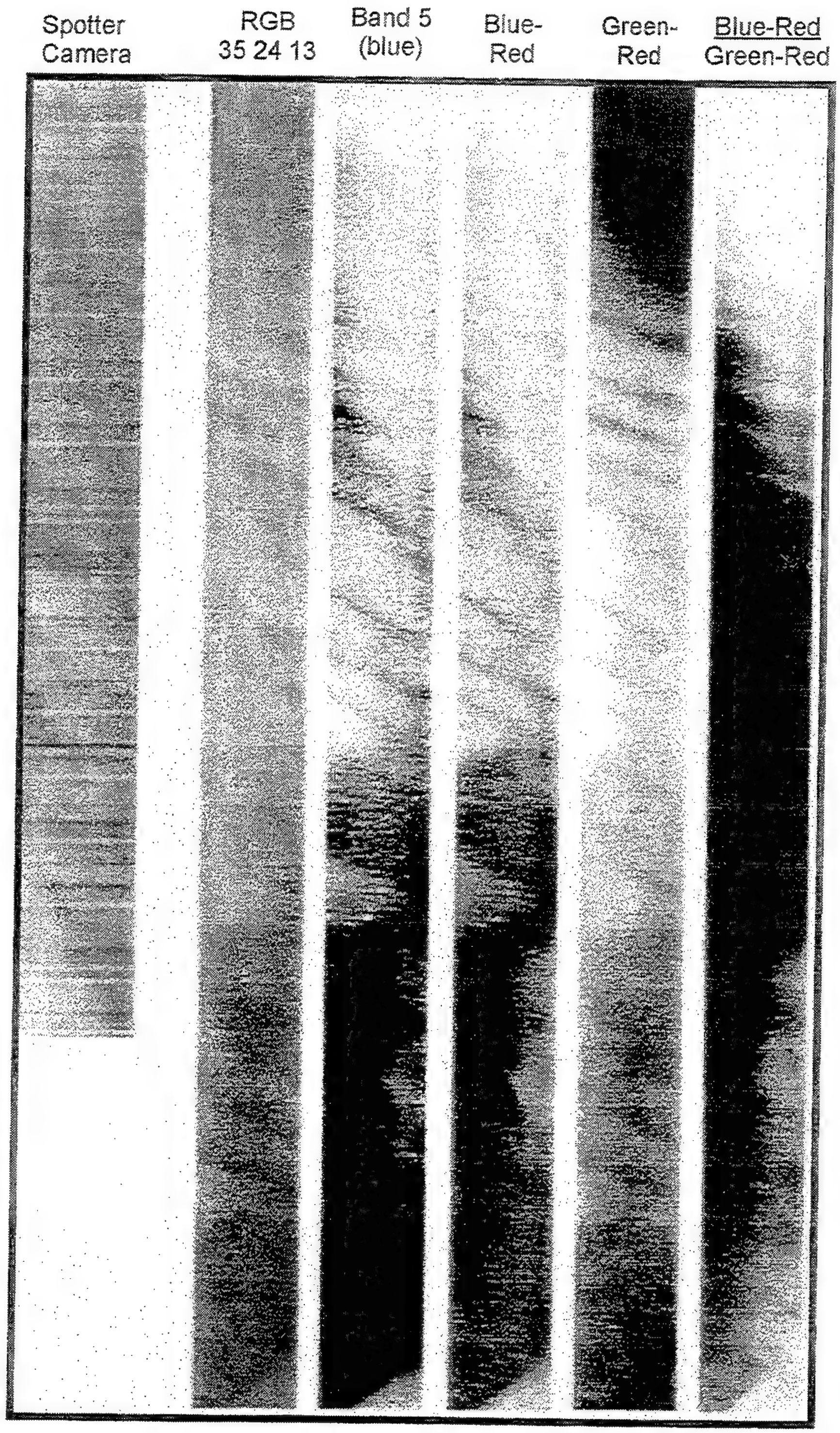



Figure 9. AAHIS Pass 13, 6 August, 1995 Color Isolation Analysis

The targets located on the beach were identified. These include our calibration panels, a sub-pixel land mine, a 25 x 7" practice bomb, and a 11 x 3" rocket warhead. Ground photos of these targets are shown in Figure 10. Figure 11 shows both spotter camera and AAHIS data collections of these beach targets on 5 August (our calibration panels were subsequently stolen before the 6 August data could be collected). Principle Component Analysis (PCA) for two overpasses of the beach targets near the calibration panels revealed all 3 of the sub-pixel targets. The bottom three images in Figure 11 show the presence of a vehicle in the calibration area as the data were collected (probably driven by the people responsible for the theft of the calibration panels later that day).

Beach targets on 6 August were identified with PCA and are shown in Figure 12. Here we see the presence of a vehicle (known) and the hood of a car (used as a reference on the beach during the test) with a sub-pixel mine deployed above it and 2 sub-pixel targets located below. All three are visible in the PCA image in Figure 12.

**Operational Notes**

Twenty-six aerial passes over the range were made on 5 August. The presence of significant cloud cover and relatively high winds produced mostly shadowed data with significant sea surface turbulence. This resulted in relatively poor data quality. Thirty-three passes were made on 6 August. There was less cloud cover and lower winds, allowing significantly improved data quality. Some problems encountered during the data collection include the following:

- We encountered inclement weather on 5 August.
- We could not fly the North part of the area on 6 August due to it being a restricted missile launch area.
- All of the targets were extremely sub-pixel (< 20 % pixel size). Larger objects (with dimensions greater than about 2 m) deployed in the shallow water area would have made the processing much more robust. This lack of larger sized objects made it difficult to calibrate the processing and procedures of the AAHIS data in the shallow water search area.
- Underwater reference calibration targets were not deployed.
- Our surface calibration panels (deployed on the beach) were stolen from the deployment site during the 5 August data collection.
- Due to airspace restrictions placed by the Pacific Missile Range Facility on the airplane collecting the data, it was not possible to get good data from the northern half of the range.
- Due to the theft of a calibration panel placed on the beach before the overflight occurred, data processing options for the collection were significantly limited.

To date, the highest spatial resolution possible is limited chiefly by the turbulence-induced motions of the aircraft. These effects are mitigated somewhat by an inertial navigation system

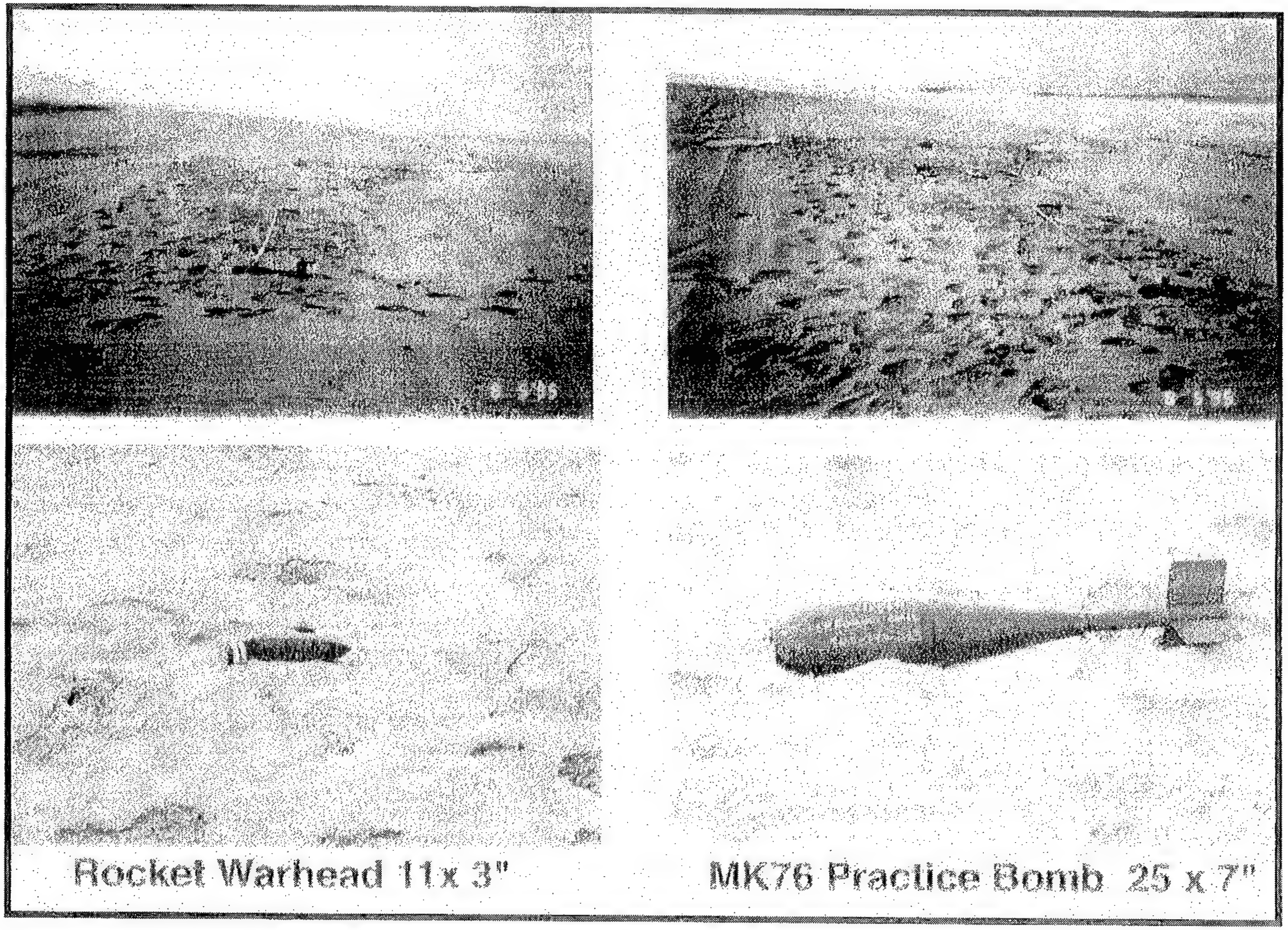



Figure 10. Beach Targets, 6 August, 1995

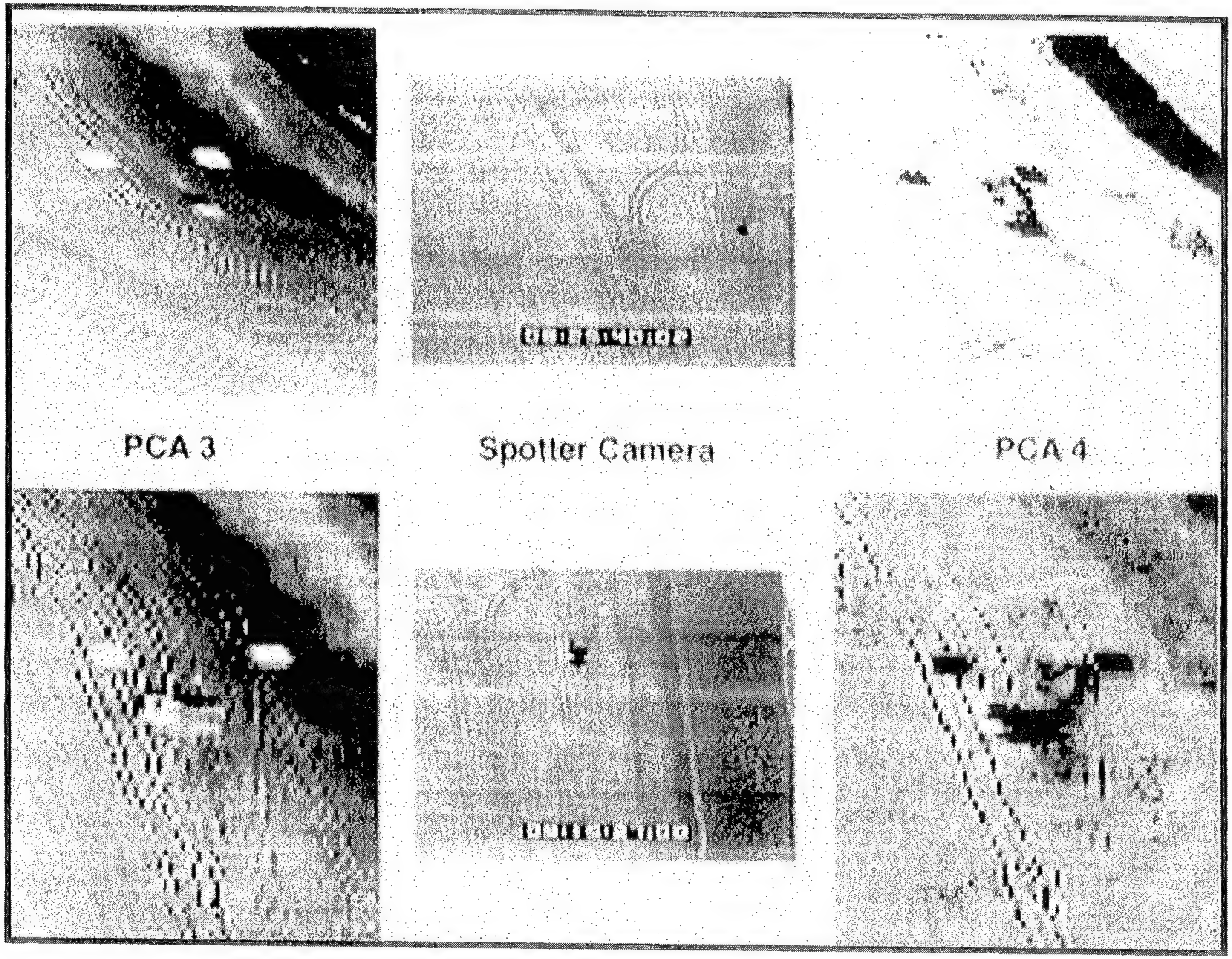
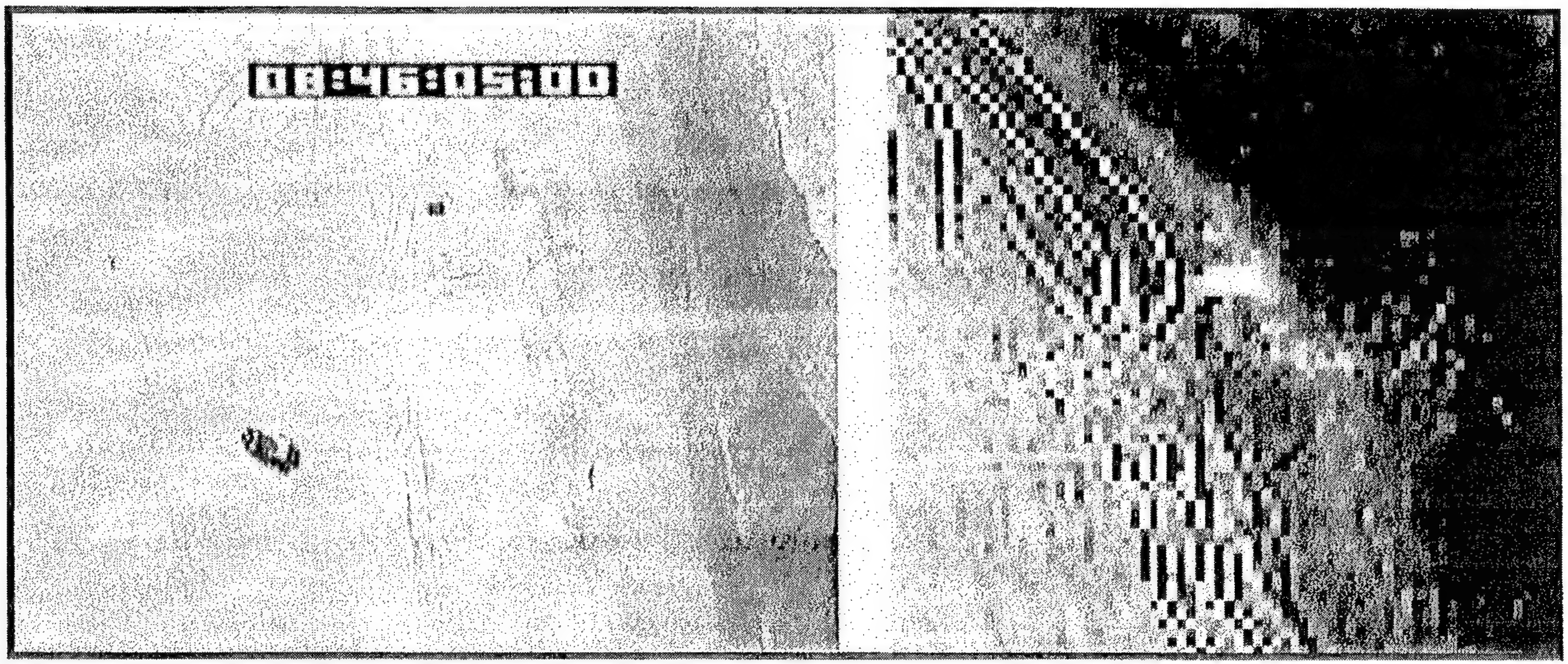



Figure 11. AAHIS Images of Beach Targets, 6 August, 1995




Spotter Camera PCA 3

Figure 12. Beach Targets and Car Hood, AAHIS, 6 August, 1995

in the aircraft, but the ultimate pixel size is presently still limited to approximately 1 m. Targets which are significantly smaller than this size can be detected when their contrast with the ambient spectral pattern is sufficiently strong to produce a significant difference between the overall spectral pattern for the pixel in which they lie and its neighbors. The threshold for such detection can be lowered somewhat if the spectral characteristics of the targets are known. The AAHIS system was successful in detecting the sub-pixel sized targets placed on the beach, because they met these criteria. The reduced spectral variability caused by sea-surface reflections and light scattering by the seawater itself, however, left insufficient contrast for confident detection of the known seabed targets. If AAHIS can improve the spatial resolution, probably through improvements in the stability of the scanner or corrections for aircraft motions, its potential for ordnance location and classification would be greatly enhanced.

## TIME-DOMAIN EM PULSE SENSOR

### System Description

The system selected for use in this project is the J.W. Fishers Mfg., Inc. Pulse 12 Time-Domain Electromagnetic Detector. This sensor is capable of detecting both ferrous and non-ferrous metals on the surface and buried less than 0.5 m. It has been extensively field tested and used by many salvage and treasure hunting operations. The system selected for use here comes an altimeter for keeping the towfish a set distance off the sea floor. This system can detect non-ferrous, but conducting objects, such as brass or other non-magnetic metals. It has a range slightly less than the magnetometer but is essential since it is quite likely that many of the targets will be non-magnetic.

### Overall Assessment

This tool was planned for use as a classification device for targets located by the other systems. However, initial testing of the sensor showed that it does not provide reproducible results which can be used for this purpose.

### Data Analysis

No further data analysis is planned for this system.

### Operational Note

The system was tested in conjunction with a Smithsonian Institution investigation of a ship wreck off the northern coast of Kaua'i. Anomalies detected with a standard proton precession magnetometer were investigated using the EM sensor, and good correlation was noted. Very small anomalies found with the magnetometer were very significant for the EM sensor, while large, probably bed-rock induced anomalies were not detected. However, when the EM sensor produced a significant signal, its baseline value shifted markedly, and it was not possible to repeat readings with any reproducibility. The tool might be useful in the future if a stable baseline can be achieved.

## CHIRP SHALLOW REFLECTION PROFILER

### System Description

During the past five years frequency modulated (i.e., "chirp") acoustic systems have undergone extensive development and are available commercially. This particular system was developed specifically for high resolution profiling of carbonate sand bodies by Lester LeBlanc and Steven Schock, the original developers of chirp acoustic instrumentation. It has a lower frequency band than the other commercially developed systems (about 500 - 1,500 Hz) and is available for local lease from the Oahu based firm Sea Engineering, Inc. It is field tested and confirmed effective in carbonate sands in Hawai`i for high resolution, shallow profiling to depths of at least 50 m. It is a prototype system, so cannot be said to be commercially available.

### Overall Assessment

Because the system by itself can retrieve data only from a very narrow swath (< 3 m) directly beneath the towfish, its application for practical ordnance location and classification depends upon the array of receivers deployed by MMTC/CSD and discussed below. The system does provide an excellent real-time characterization of the seabed type, however, which was very useful in this project for confirming the soft-substrate types identified by the SeaBat® back-scatter records.

### Data Analysis

No analysis of the data retrieved directly by the chirp transducers is planned. Comparison of the system with the GeoPulse® as an appropriate sound source is described below.

### Operational Note

The Sea Engineering system proved to be a very well designed and robust system. Its only negative attribute is the size and weight of the towfish (~4' X 5' X 3'; 800 lb. in air) , which make deployment and recovery much more difficult than other systems and require special handling for shipment.

## SEISMIC PROFILING

### System Description

This system, developed and tested by MMTC/CSD, is basically a cross between a high resolution shallow profiling system and a reduced-scale 3-D oil-field seismic system. It is composed completely of components which are commercially available. An ORE Geopulse® sound source is used to generate an impulse with a spectrum between 500 to 2,500 Hz within 3 db of maximum output. It can be triggered at 0.25 second intervals to provide seabed and

sub-surface resolutions of approximately 0.5 m. It penetrates the seabed and retrieves useful returns to depths of more than 50 m in carbonate sands.

A specially designed 24-channel hydrophone array receives the reflected energy from this source. It is constructed in three separate segments of eight channels each, with 1 m group intervals. This can produce the 0.5 meter along-track common depth points for signal stacking. The three-hydrophone groups are tightly spaced so that, while they effectively cancel random noise, no high frequency signal loss occurs at extreme angles of incidence. An Elics Delph24® processing system is used to receive and digitize the data. This system can sample 24 channels at 12 kHz, sufficient for anti-aliasing the broad-band Geopulse® signals.

**Overall Assessment**

Reduction of multi-channel seismic data for high resolution imaging is computationally intensive and not possible to complete in real-time or for a quick look given the hardware and personnel available for this project. Processing of the data has been initiated at MMTC/CSD, and will be reported independently to NFESC. Monitoring of the field acquisition showed that excellent data were collected. Field modifications in the system and favorable sea states combined to produce good conditions for the exercise.

## REFERENCE CITED

Gerritsen, F. 1978. Beach and Surf Parameters in Hawai`i. University of Hawai`i Sea Grant Program Technical Report UNIHI-SEAGRANT-TR-78-02, 178 p.

# APPENDIX G

# SEISMIC SURVEY FINAL REPORT

# Classification and Mapping of Underwater UXO

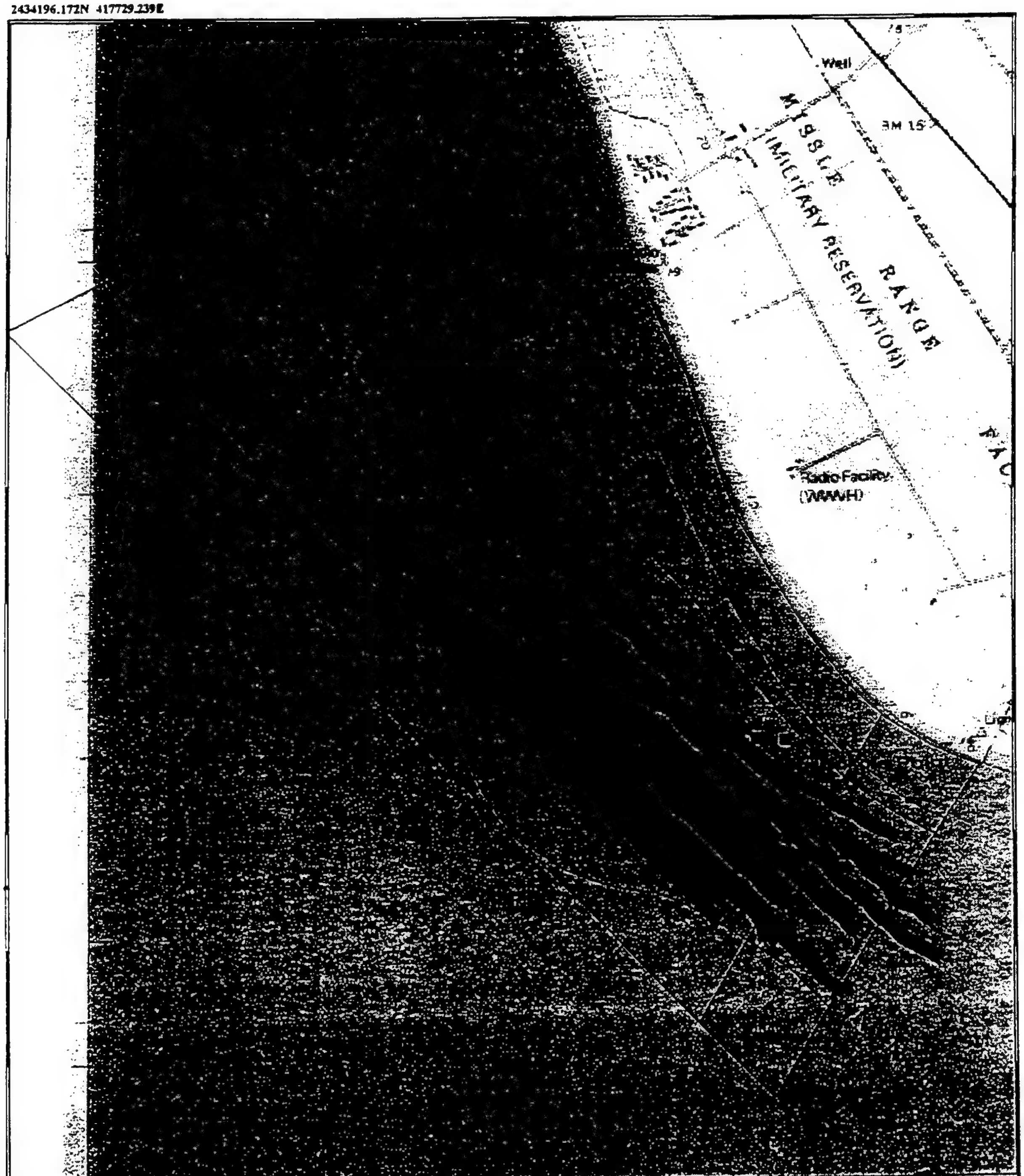
Seismic Survey Final Report

## Demonstration Activities

Marine Minerals Technology Center, Continental Shelf Division
The University of Mississippi

# UXO Survey Site and Seismic Track Lines

2434196.172N 417729.239E




2427756.172N 422609.239E

| | |
|---|---|
| Projection | UNIVERSAL TRANSVERSE MERCATOR |
| Datum | North American Datum (1983) / WGS Datum (1984) |
| Zone Number | 4 |
| Hemisphere | North |

SCALE = 1 : 24000

1000 m

1000 ft

N

Figure 1

# UXO Seismic Track Line 5a

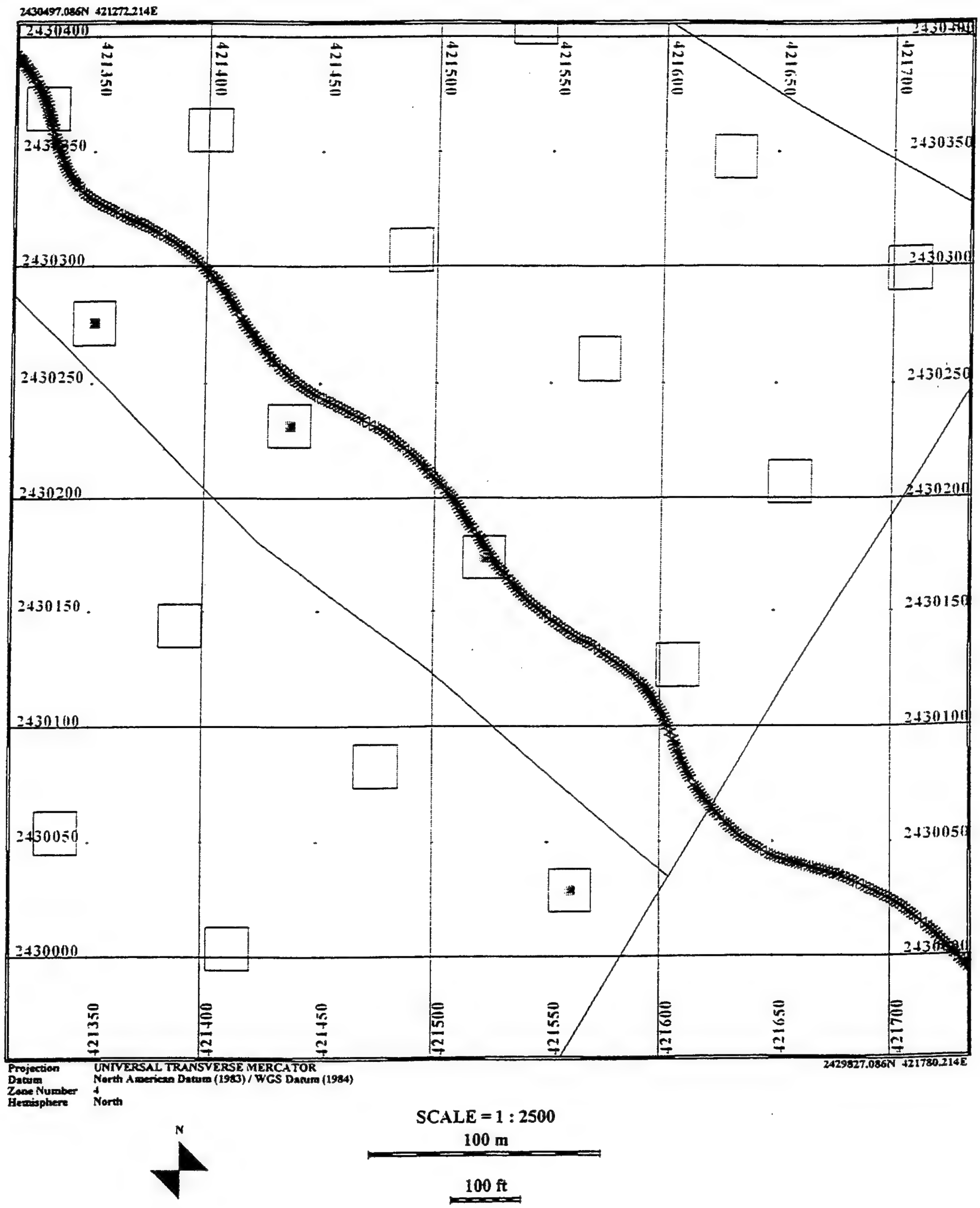
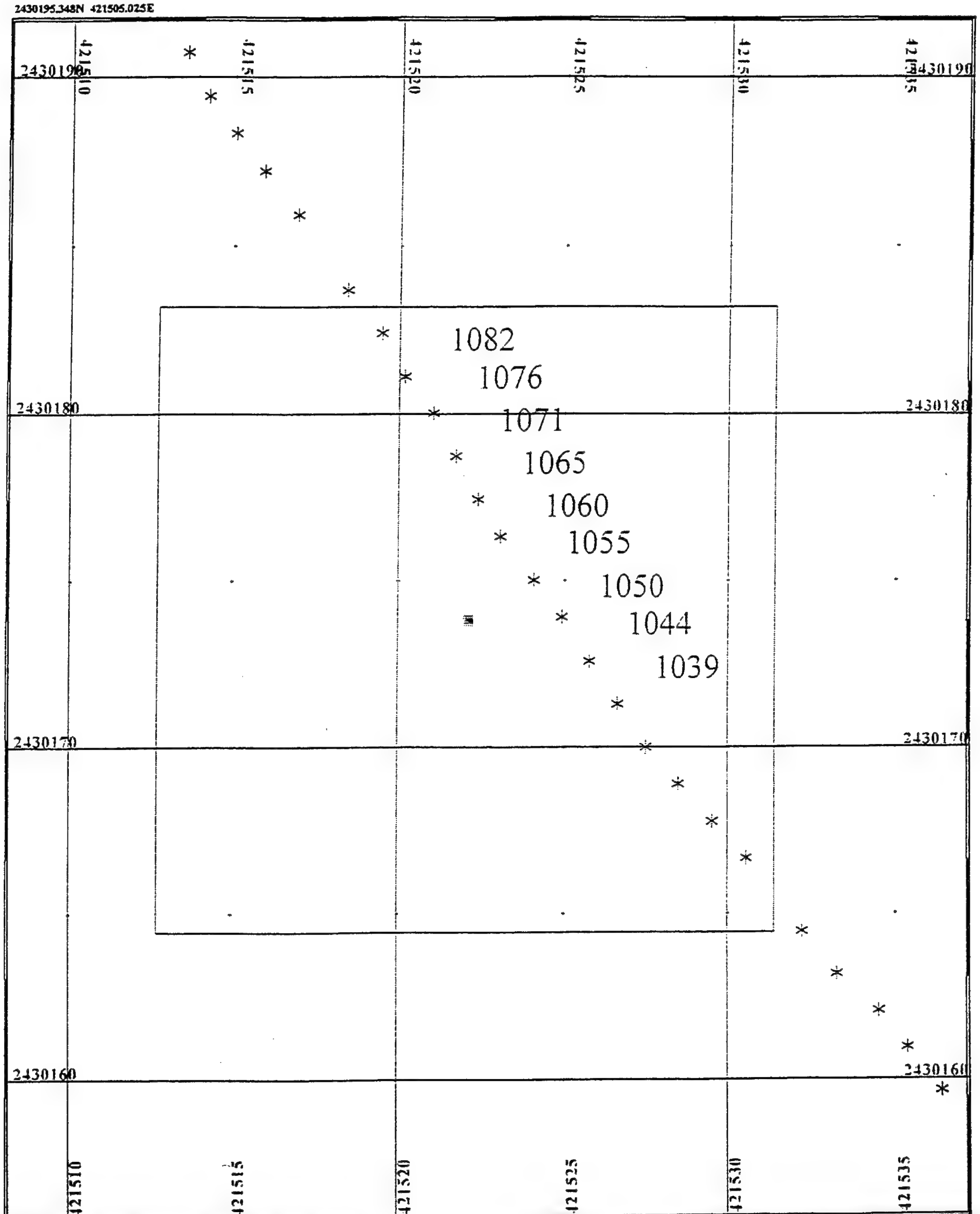



Figure 2

# UXO Seismic Track Line 5a (Zoom In)




Projection UNIVERSAL TRANSVERSE MERCATOR
Datum North American Datum (1983) / WGS Datum (1984)
Zone Number 4
Hemisphere North

SCALE = 1 : 175

N

10 m

50 ft

Figure 3

## Acquisition Hardware

For purposes of discussion, a seismic acquisition system can be thought of as three devices: a sound source, a receiver, and a recording system. For the small object application, all devices must be designed to handle high bandwidth as well as high frequencies. The sound source used was an ORE Geopulse. Typically referred to as a boomer plate, the Geopulse delivers coherent noise in the range of 100 - 5000 Hz. It is deployed on the surface using a PVC catamaran as a tow vehicle. The boomer location is figured as a constant layback from the GPS antenna. It's lateral offset is also assumed constant. Shot point locations are then considered to be at the midpoint between the boomer and a given receiver.

The receiver groups for this survey were Innovative Transducers, Inc (ITI) Trout hydrophone arrays. ITI was contracted to build custom multichannel arrays for this project, but the arrays were not delivered until after the survey. The reason for choosing ITI as the source for the receiving arrays was three fold. First, ITI was the only array manufacturer that could demonstrate that their elements could receive the entire bandwidth produced by the Geopulse. Second, ITI's unique solid array design makes them less susceptible to physical noise than oil filled arrays. And finally, the ITI arrays are solid and contain no oil, making them ideal for use in environmentally sensitive areas.

Since the multichannel arrays were unavailable at the time of the survey, four single channel arrays were used in their place. These arrays were towed on three meter cross track spacings behind the boomer. To increase the near subsurface resolution, only the first three elements of each array were used. So, in a sense, the survey consisted of four simultaneous single channel surveys.

The recording system used was an Elics Delph24 PC based acquisition system. This device consists of standard PC components along with A/D hardware and software capable of sampling 24 channels at 12000 Hz . Since only four arrays were deployed, the system was configured to sample six channels at 24000 Hz, insuring over sampling. Data were recorded on a hard disk and later transferred to an Exabyte tape for storage. Acquisition parameters for the Delph24 are shown in Figure 4.

## Deployment

The original survey design called for 3 six-channel arrays and one 36-channel array configured to deliver a 3-D survey with bins of one half meter along track and one and a half meters across track. This design is shown in Figure 5. As noted above, however, the multichannel arrays were not available at survey time making it necessary to devise an alternate plan. The final deployment consisted of 4 single channel arrays in the same geometry. Naturally, there was no possibility of doing multifold processing with this configuration. This resulted in diminished signal to noise ratios and a poor quality data set.

Line name : D:\SEISSA ( REVERSE - 50 shot/inch - 5 ms/inch ) 1

Mode : PLAYBACK
Start/End of line : 00/00/0000 00:00 ... XX/XX/XXXX XX:XX

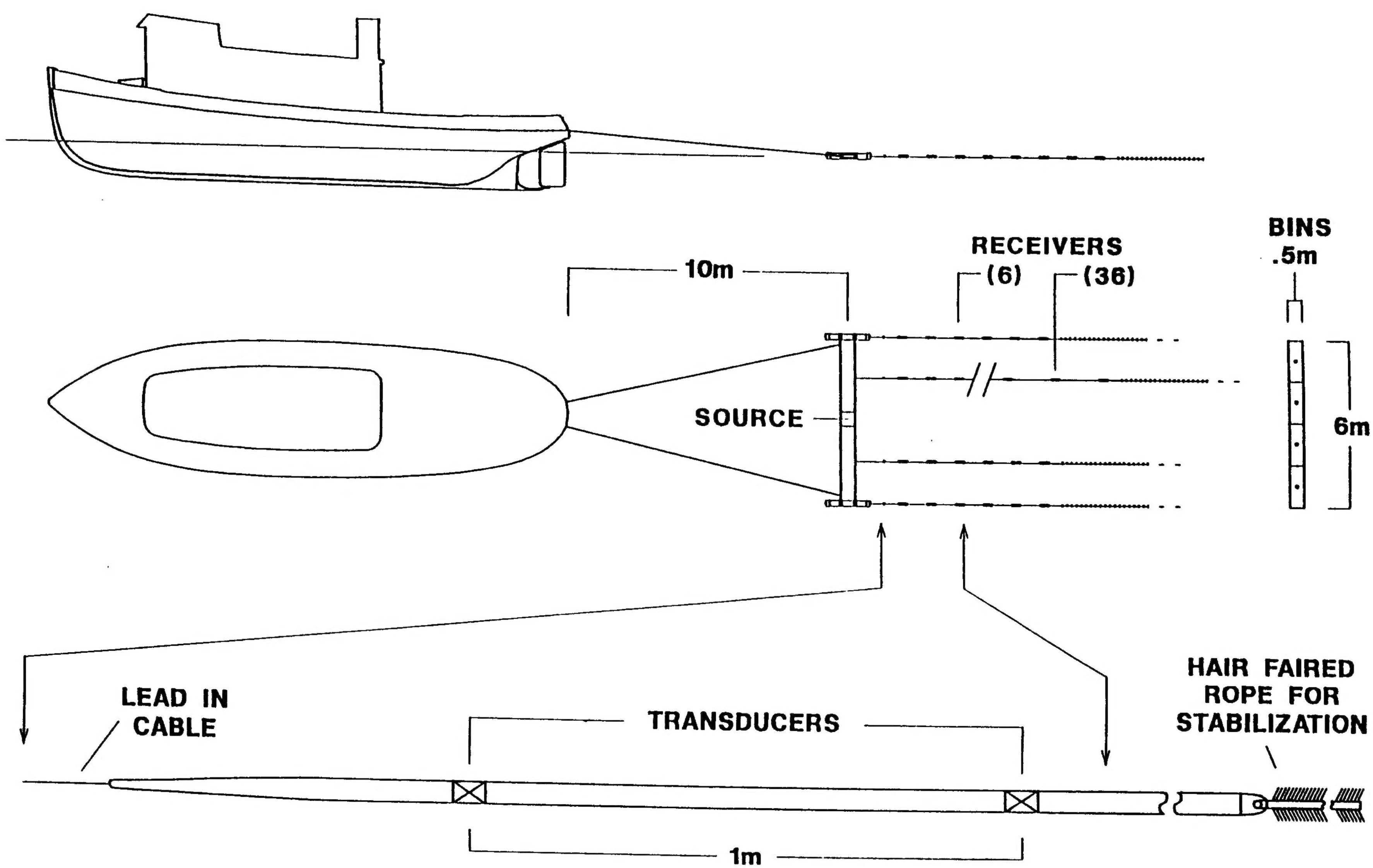
Ship name/Job ID : - / -
Source layback/depth : 0m / 0m
Number of sources in array : 1
Source type/ID : - / 0
Receiver layback/depth/ID : 0m / 0m / 0

| | | | | |
|---|---|---|---|---|
| Acquisition | | Swell filter | OFF | Levels |
| Shooting interval : | 500 ms | Sea bed window : | 0.1 ms | Chan 01 : 5000.0mV |
| Recording length : | 80 ms | Sea bed trigger : | 0.0 mV | Chan 02 : 5000.0mV |
| Recording delay : | 0 ms | Sea bed trigger adj. step : | 1.0 mV | Chan 03 : 5000.0mV |
| Auxiliary Recording delay : | 0 ms | Sea bed time : | 0.1 ms | Chan 04 : 5000.0mV |
| Sampling frequency : | 24000 Hz | Sea bed time adj. step : | 0.2 ms | Chan 05 : 5000.0mV |
| Synchronization type : | MASTER | Flat sea bed : | OFF | Chan 06 : 5000.0mV |
| Number of channels : | 6 | Filter operator : | 1 | Chan 07 : ----.-mV |
| Number of auxiliary channels : | 0 | | | Chan 08 : ----.-mV |
| Gain setting : | MANUAL | Time varying filter | OFF | Chan 09 : ----.-mV |
| Ground references : | SING. | Start low cut : | 0 Hz | Chan 10 : ----.-mV |
| | | Start high cut : | 12000 Hz | Chan 11 : ----.-mV |
| Filters | | End bandwidth depth : | 42 ms | Chan 12 : ----.-mV |
| High pass filter : | 1920 Hz | End low cut : | 0 Hz | Chan 13 : ----.-mV |
| Low pass filter : | OFF | End high cut : | 12000 Hz | Chan 14 : ----.-mV |
| Zero phase filters : | OFF | | | Chan 15 : ----.-mV |
| | | Predictiv deconvolution | OFF | Chan 16 : ----.-mV |
| Automatic gain control | ON | Length of signature : | 0.1 ms | Chan 17 : ----.-mV |
| Automatic gain control : | A00 | Length of processing window : | 0.1 ms | Chan 18 : ----.-mV |
| Up time : | - | Coefficient of filter : | 3 | Chan 19 : ----.-mV |
| Down time : | - | Position of multiple : | 20.8 ms | Chan 20 : ----.-mV |
| Start gain : | - | Length of processing : | 42 ms | Chan 21 : ----.-mV |
| End gain : | - | | | Chan 22 : ----.-mV |
| Time increment : | - | Spiking deconvolution | OFF | Chan 23 : ----.-mV |
| Time decrement : | - | Length of signature : | 0.1 ms | Chan 24 : ----.-mV |
| Gain increment : | - | Wave identification : | 1 | |
| Gain decrement : | - | | | Copyright ELICS 1992. DELPH |
| AGC window width : | 0.3 ms | Horizontal stacking | ON | |
| | | Number of shots : | 2 | |
| Standard ID channel (acq./play.) | | | | |
| First shot number : | 900 | Stack-CDP | OFF | |
| File format : | ELICS | Stack coverage : | OFF | |
| Device : | DISK | Channels validity : | 100000 | |
| Data format : | - | First channel : | 1 | |
| Media density : | - | | | |

Figure 4

Figure 5

Array Configuration for High Resolution 3-D and Amplitude Variation with Offset Processing



Tape Contents

| FILE | NAME | LINE | SOURCE | FORMAT |
|---|---|---|---|---|
| 1 | chr05 | 5 | chirp | SEGY-I |
| 2 | chr14 | 14 | chirp | SEGY-I |
| 3 | chr04 | 4 | chirp | SEGY-I |
| 4 | chr13 | 13 | chirp | SEGY-I |
| 5 | chr21a | 21 | chirp | SEGY-I |
| 6 | seapig1 | 1 | chirp | SEGY-I |
| 7 | seapig2 | 2 | chirp | SEGY-I |
| 8 | seapig4 | 4 | chirp | SEGY-I |
| 9 | seapig5 | 5 | chirp | SEGY-I |
| 10 | gp03 | 3 | boomer | SEGY-I |
| 11 | gp01 | 1 | boomer | SEGY-I |
| 12 | gp03 | 3 | boomer | SEGY-I |
| 13 | gp12 | 12 | boomer | SEGY-I |
| 14 | gp1a | 1 | boomer | SEGY-I |
| 15 | gp01 | 1 | boomer | SEGY-I |
| 16 | ge10 | 10 | boomer | SEGY-I |
| 17 | ge02 | 2 | boomer | SEGY-I |
| 18 | ge11 | 11 | boomer | SEGY-I |
| 19 | ge03 | 3 | boomer | SEGY-I |
| 20 | ge14 | 14 | boomer | SEGY-I |
| 21 | ge13 | 13 | boomer | SEGY-I |
| 22 | ge08 | 8 | boomer | SEGY-I |
| 23 | ge12 | 12 | boomer | SEGY-I |
| 24 | ge07 | 7 | boomer | SEGY-I |
| 25 | ge11a | 11 | boomer | SEGY-I |
| 26 | ge06 | 6 | boomer | SEGY-I |
| 27 | ge04 | 4 | boomer | SEGY-I |
| 28 | shl01 | 1 | boomer | SEGY-I |
| 29 | shl06 | 6 | boomer | SEGY-I |
| 30 | shl02 | 2 | boomer | SEGY-I |
| 31 | shl10 | 10 | boomer | SEGY-I |
| 32 | shl09 | 9 | boomer | SEGY-I |
| 33 | seis5a | 5 | boomer | SEGY-I |
| 34 | seis6 | 6 | boomer | SEGY-I |
| 35 | seis1a | 1 | boomer | SEGY-I |
| 36 | seis4a | 4 | boomer | SEGY-I |
| 37 | seis5b | 5 | boomer | SEGY-I |
| 38 | seis2 | 2 | boomer | SEGY-I |
| 39 | seis20 | 20 | boomer | SEGY-I |
| 40 | seis10 | 10 | boomer | SEGY-I |